T H E M E  I S S U E

ZERO-ENERGY MASS CUSTOM HOME RESEARCH PARADIGMS

Guest Editor:
Dr Masa Noguchi
MEARU (R&D ZEMCH Group), Mackintosh School of Architecture, The Glasgow School of Art, UK

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To achieve its aims, the OHIA organizes and co-ordinates a number of activities which include the publication of a quarterly journal, and, in the near future, an international seminar and an annual competition. The Association has the more general aim of seeking to improve the quality of built environment through encouraging a greater sharing of decision-making by ordinary people and to help develop the necessary institutional frameworks which will support the local initiatives of people in the building process.

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Edited by Nicholas Wilkinson RIBA, Eastern Mediterranean University, North Cyprus. DPU Associate, University College London, UK. nicholaz.wilkinson@emu.edu.tr
UNVEILING CONTEMPORARY URBAN TRANSFORMATIONS IN THE ARABIAN PENINSULA
Dynamics of Global Flows, Multiple Modernities, and People-Environment Interactions

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Cities on the Arabian Peninsula are witnessing dramatic transformations that represent different trends resulting from attempts to realize global aspirations. With many architectural interventions and design ideas associating such an intensive development process, this issue of Open House International addresses the dynamics of global flows, multiple modernities, and people-environment interactions as reflected in the urban environment of cities on the Arabian Peninsula. This edition is not exclusively about the history of settlements in the peninsula, it concerns itself with architecture and place typologies developed over the past two decades. Raising a number of questions, articles are centered on answering key questions and responding to key challenges. This includes impact of globalization, urban identity, sustainable urbanism, socio-cultural encounters, and socio-global aspirations.

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Editorial

In response to growing global warming issues and the constant increase of energy prices, housebuilders and housing manufacturers today are becoming more responsive to the delivery of net zero energy and carbon dioxide (CO₂) emission sustainable homes than ever. Within this context, the sustainability may embrace housing economy and adequacy beyond the legitimacy in which the quality barely coincides with individuals’ dynamic various needs, desires and expectations. Nevertheless, the industry’s business operation tends to follow routines and the close system mode of operation often hinders the enterprises from adopting unfamiliar innovations which may be inevitable in realising the delivery and operation of socially, economically and environmentally sustainable homes.

In this special issue, the notion of ‘mass customisation’ was reviewed. This paradoxical concept has been recognised as a means to lessen production costs of end-user products whilst achieving the customisability through economies of scope rather than economies of scale. Housing is no exception. The idea dates back to the 1950s as the gravity became explicit in Walter Gropius’ book entitled ‘Scope of Total Architecture.’ The essence of mass customisation applied to housing was speculated as he emphasized the need for ‘standardising and mass-producing not entire houses, but only their component parts which can then be assembled into various types of houses.’ In fact, housing is a system of energy and environment, composed of a number of parts and components indeed. The choice of the housing design elements need to be made carefully with due consideration of the project’s initial and operational cost, quality, and time. Moreover, the location factor cannot be less of a consideration as it encompasses geographical and topographical conditions and local regulations. Location and orientation of housing help secure the optimum use or prevention of sunlight and wind and this affects the building’s operational energy consumption and generation which correlate with CO₂ emissions and utility costs.

Mass Customisation is an oxymoron. The term is composed of two opposite notions: mass production and customisation. The notion was anticipated in 1970 by Alvin Toffler in his book entitled ‘Future Shock.’ In 1987, the term was eventually coined by Stanley M. Davis in his book entitled ‘Future Perfect.’ Furthermore, in 1993, Joseph B. Pine II profoundly systematized the general methods of mass-customizing products and services in his book entitled ‘Mass Customization.’ In 2009, Frank T. Piller and Mitchell M. Tseng edited a ‘Handbook of Research in Mass Customization and Personalization’ and compiled the R&D activities and outputs delivered by a variety of industries across the globe. The handbook also includes one of the successful mass customization approaches being applied to the housing industry—i.e. modularization of building components. The total number of possible ordered pairs (or combination) of given standard housing components can be quantified. In the approach, the mass customization (MC) has been systematized and visualised simply by making use of a conceptual analogue model as follows: MC = f(PS). In this model, the service sub-system (S) concerns communication platforms that lead the users to participate in customizing their design output while the product sub-system (P) covers production techniques that aim to encourage the standardization of housing components for mass production and dissemination. Standardisation of building components seems to be a limited hindrance to design customisation if communication platforms are well developed. Design-consulting staff and appropriate communication interface are required to facilitate user choice of standard design components. These fundamental design service factors can also be integrated into a comprehensive model: S = f(l, p, t).

In this model, the service sub-system (S) is supported by the existence of the location (l), personnel (p) and tool (t) factors and they are necessarily interrelated. Basically, building components can be divided into three categories: volume, exterior and interior. These can be considered the main elements of the product sub-system (P) which can be explained by the following conceptual model: P = f(v, e, i, o). The volume (v) components are used to configure the building’s internal space that determines the size and location of each room while the interior (i) and exterior (e) components serve to co-ordinate decorative and functional elements that customize a building. In addition, ‘o’ denotes other optional features such as building amenity and security systems, inclusive design components and renewable energy technologies. In general, fabric and ventilation heat losses are associated with building volume and envelop exposures whilst thermal transmittance links up with materials applied to exterior and interior components.
Most of the net zero-utility-cost housing manufacturers typically in Japan have begun to install a number of renewable energy technologies as standard features rather than options based on their value-added, high cost-performance marketing strategy. The strategy itself is far from new having been applied to a variety of end user products around the world. For instance, although today’s automobiles can be produced with lower production costs than those in the past, their selling price does not seem to be affected dramatically by higher productivity. New cars are still generally regarded as expensive; nevertheless, the list of items now offered as standard in new cars, such as air conditioning, a stereo set, airbags, remote-control keys, power steering, power windows and adjustable mirrors, were offered only as expensive options in older models. Clearly, the quality of newer models is much higher than that of older models. The same is true for the housing industry. Quality-oriented production contributes towards the delivery of high cost-performance housing in which high-tech modern conveniences that are installed as options in conventional homes are available as standard equipment (Se). In this context, the product subsystem (P) can further be modified into the following conceptual model: \( P = f (v, e, i, o) + Se \). In fact, Japanese housing manufacturers mass-produce net zero-utility-cost customizable homes in which a variety of housing amenities and renewable energy and environmental technologies (e.g. PV, air source heat pump, micro combined heat and power systems, and energy monitoring and control equipment linked to a large-scale lithium-ion battery) tend to be installed as standard features rather than options. Despite the reduction of equipment choices, volumetric, exterior and interior design components still remain substantial options from which the users can choose so as to customize the end product.

In order to deliver a marketable and replicable zero energy/emission mass custom home, or ZEMCH, the strategic balance between the optional and standard features seems to be critical. The optional features may be provided with the aim to enhance design quality (or customizability) that helps contribute to satisfying desires and expectations of individual stakeholders. The standard equipment, on the other hand, needs to be installed in buildings as it aims to exceed product quality whose levels can be adjusted in conjunction with societal demands and requirements. This edition encompasses a wide spectrum of hopes and fears around the design, production and marketing approaches to the ZEMCH delivery and operation, and showcases some exemplars budding out in different climates around the globe. This issue is developed in collaboration with ZEMCH Network and the International Energy Agency (IEA) Solar Heating and Cooling (SHC) Task 40 & Energy Conservation in Buildings and Community Systems (ECBCS) Annex 52 joint implementing programme experts with the aim to solidify today’s diverse expertise in the realm as elicited research paradigms for further exploration and delivery of the homes that meet the wants and needs of individuals and society.

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Introduction

Zero-energy buildings have gained more attention since the publication in 2010 of the recast Energy Performance of Buildings Directive (EPBD 2010). The Directive requires that by 31 December 2020 all new buildings should meet higher levels of performance than before in order to ensure that they are nearly zero-energy buildings. Building designers should aim to achieve this outcome by exploring more of the alternative energy supply systems available locally using cost-efficiency assessment and without compromising the comfort for the building users.

A “nearly zero-energy building” refers to a high energy performance building where annual primary energy consumption is provided to a very significant extent by energy from renewable sources, being energy from renewable sources produced on-site, or nearby or both. Since the Directive does not specify minimum or maximum harmonized requirements nor details of the energy performance calculation framework, it is up to the Member States to define the exact meaning of “high energy performance” and “amount of energy from renewable sources” according to their own local conditions and strategic interests. Nearly zero-energy performance derives from the net zero-energy concept which, in the case of buildings, is usually defined as a high energy performance building that over a year is energy neutral (i.e. net balance of primary energy is 0 kWh/(m² y)). Therefore, a possible way to assess the nearly zero-energy performance is by analysing the annual energy balance in Net Zero-Energy Buildings.

Net Zero-Energy Buildings have been the object of numerous studies in recent years as various countries have set this performance as a long-term goal of their energy policies (Ayoub 2009, Aelenei et al. 2011, Sartori et al. 2012).
International Energy Agency collaborative research initiative between the Solar Heating and Cooling (SHC) and the Energy Conservation in Buildings and Community Systems (ECBCS) through Task 40/Annex 52 - “Towards Net-Zero Energy Solar Buildings”, summarises most of the recent developments in the field (IEA 2008). The Task members, including approximately 55 National Experts, among which can be found the authors of this work, together with another 25 regular participants and contributors, are currently researching examples of: net-zero, plus energy and near net-zero energy buildings in order to develop:

- a common understanding of NZEBs,
- a framework of harmonized international definitions, analysis tools,
- examples of innovative solutions and
- industry guidelines for the design of NZEBs.

NZEB performance

In the international context, there are four main types of NZEBs:

- Net Zero Site Energy,
- Net Zero Source Energy,
- Net Zero Energy Cost and

Net Zero Site Energy means that the annual balance is based on the grid interaction at the boundary of the building site, i.e. the overall energy delivered to the building from the utility grid is offset by the overall energy fed back into the grid.

The Net Zero Source Energy definition is the one that most closely matches the EPBD recast in a nearly zero-energy context (EPBD 2010). IN this definition the energy (delivered from and feed into the grid) has to take into account primary energy conversion factors.

The Net Zero Energy Cost definition is based on an economic balance (the energy bills of a building are equivalent the amount of money the utility pays the owner for renewable energy the building feeds to the grid).

The Net Zero Energy Emissions building on an annualised basis these produce and export at least enough emissions-free renewable energy to equal the total emissions that were caused in the importation and use of emission-producing sources on an annual basis (Torcellini 2006).

As with all buildings the design and realisation of a Net Zero Energy Building includes many different possible combinations of building envelope, utility equipment and on-site energy production equipment able to achieve net-zero energy performance. Further influencing the design is a need to consider the balance boundary, which defines which consumers are included in the balance. Despite these variables there is some consensus that zero energy building design should start from passive sustainable design as this NZEB level of performance is achieved as a result of executing two fundamental approaches; (a) reducing building energy demand and (b) generating electricity or other energy sources to get enough off-sets to achieve the desired energy balance (Fig. 1) from renewable energy systems (RES). As one can easily imagine passive approaches play a crucial role in addressing NZEB design as they directly affect the heating, cooling, ventilation and lighting loads of the building’s mechanical and electrical systems and, indirectly, the strive for renewable energy generation.

Case Studies

Table 1 presents a summary of the main technical features of the 9 projects selected from the IEA Task 40 project data base for analysis (Musall 2012). As can be seen from Table 1 buildings are characterised according to location, conditioned floor area, climate challenge and primary energy performance (consumption versus supply). In the case of the climate challenge it should be noted that these case studies correspond to only two different categories of climate challenges; heating dominated and heating & cooling dominated.

These nine projects were selected as case studies based on criteria such as; access to technical documentation regarding physical characteristics, availability of monitored and/or simulated energy performance data, as well as the authors access to lessons learned about designing, operating, and post-evaluation processes.

Reference to Figure 1 below shows that, in terms of Net Zero Energy performance, of these nine buildings six are plus-energy buildings and three are nearly zero-energy buildings (Fig. 1).

Two of the three projects exhibiting a near zero-energy performance, Leaf, was initially designed to meet net zero-carbon performance (Musall 2012) whereas Lima and Ecoterra, were designed to be energy efficient to minimise negative impacts on the environment (Noguchi et al. 2008). One should be mindful that Lighthouse, which is a demonstration building, was also designed as net zero-carbon, being the UK’s first house that also meets Level 6 (the highest level) of the Code for Sustainable Homes (Department for Communities
and Local Government 2009).

### NZEB Design Features

Although the main principles applied in passive sustainable design are well known, the fundamental issue here is to find if the same principles can also be applied in NZEB design given the other RES imperatives. To discover the answer, an analysis of the nine case studies was performed according to the scheme shown in Figure 2. Figure 2 illustrates that the first principle in the NZEB design focuses on reducing the amount of energy needed through passive approaches, (inner circle of the chart). Given the inherent needs of artificial lighting and possible heating and/or cooling, the second principle aims at implementing energy efficient systems, (second circle of the chart). The renewable energy systems are needed to offset in large measure the energy demand required for lighting, heating and cooling (the third principle). However, rather than performing a detailed analysis of each of the projects, a cross examination was performed instead. This procedure is expected to allow for the identification of the set of relevant NZEB design issues (combination of passive approaches (PA), energy efficient systems (EES) and renewable energy systems (RES)) which are more likely to succeed in reaching the desired energy performance.

In the sections to follow an overview of the key components arising from these principles and which affect NZEB energy performance will be presented for each of the three research components, passive approaches, energy efficient systems and renewable energy systems.

#### First Principle: Passive Design

As noted above, passive approaches play a fundamental role in NZEB design as they directly affect the loads put on the building’s mechanical and electrical systems, and indirectly, the strive for renewable energy generation. In this context it is understandable why zero energy building design should start from passive sustainable design thinking and approaches. In this respect, and even though the buildings were designed to meet different energy performance levels (according to national specific strategic needs), the first characterisation focuses on envelope thermo-physical characteristics and compactness (Table 2).

In general, passive solar energy concepts fall into three main categories/challenges depending of the solar energy exploitation (heating, cooling, lighting/appliances) and the relative strategies used (prevention, modulation, rejection/collection,

<table>
<thead>
<tr>
<th>Building Name and Location</th>
<th>Conditioned floor area [m²]</th>
<th>Climate challenge</th>
<th>Annual Energy Consumption [kWh/m²·y]</th>
<th>Annual Energy Supply [kWh/m²·y]</th>
<th>Annual Energy Balance [kWh/m²·y]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Quebec, Canada</td>
<td>234</td>
<td>Heating</td>
<td>50.80</td>
<td>16.35</td>
<td>-34.45</td>
</tr>
<tr>
<td>Energy House Denmark</td>
<td>216</td>
<td>Heating</td>
<td>90.93</td>
<td>108.3</td>
<td>18.0</td>
</tr>
<tr>
<td>Leaf House Italy, Italy</td>
<td>477</td>
<td>Heating &amp; Cooling</td>
<td>151.24</td>
<td>128</td>
<td>-23.24</td>
</tr>
<tr>
<td>Lima, Spain</td>
<td>45</td>
<td>Heating</td>
<td>79.8</td>
<td>81.56</td>
<td>-1.76</td>
</tr>
<tr>
<td>Rofen, Switzerland</td>
<td>315</td>
<td>Heating</td>
<td>62.86</td>
<td>85.08</td>
<td>22.22</td>
</tr>
<tr>
<td>Riverside, Canada</td>
<td>234</td>
<td>Heating</td>
<td>38.90</td>
<td>42.40</td>
<td>3.50</td>
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<tr>
<td>Light House UK</td>
<td>79</td>
<td>Heating</td>
<td>166.92</td>
<td>191.54</td>
<td>24.62</td>
</tr>
<tr>
<td>Plus Energy House Austria</td>
<td>855</td>
<td>Heating</td>
<td>129.20</td>
<td>150.4</td>
<td>20.9</td>
</tr>
<tr>
<td>Plus Energy House Germany</td>
<td>7890</td>
<td>Heating</td>
<td>70.65</td>
<td>113.95</td>
<td>-43.3</td>
</tr>
</tbody>
</table>

Table 1. Case studies - common parameters considered.
Thermo characteristics (U-values and g-values)

In order to have a clearer picture of the values shown in Table 2, and using Passive House standard as reference, one can represent graphically the physical thermo-characteristics of building envelopes (Fig.3, Fig.4 and Fig.5). Figure 3 shows the range of thermal transmittances (U-values) found in the opaque envelope of selected case studies. Most projects under analysis present values as low as the Passive House example included as a reference for comparison purposes. One interesting feature shown in Figure 3 is that all buildings dealing with heating and cooling challenges are characterised by U-values greater than the one indicated by the Passive House standard.

With respect to windows, the Case Study U-values vary between 0.70W/m²K and 1.35W/m²K, which suggests low values that are very close to Passive House standard. An interesting feature regarding U-value of windows is that the projects with best net zero-energy performance (i.e. Plus Energy Settlement, Plus Energy Houses, Riehen and Lighthouse) are characterised by lower U-value of windows compared with the rest of the buildings.

As for the g-values, all buildings, with the exception of Lima and EnergyFlexHouse, are characterised by values higher than the 50% minimum stipulated by the Passive House standard that we have used as reference. Considering a combination of the U-value and g-value of windows, it is well known that they must be balanced according with the building’s climate challenge. Low U-values in conjunction with high g-values are appropriate for a cold climate given that this arrangement promotes high heating performance. Bearing this in mind it is no surprise that the U-values and g-values of Lima are, respectively, higher and lower, than the rest of the case study projects given that Lima faces combined heating and cooling challenges.

Compactness

An important role in a building’s heat modulation and distribution is played by ratio of thermal heat loss surface area of envelope (A) to heated volume (V) or, in other words, compactness. Typically, a high compactness (for small residential buildings

<table>
<thead>
<tr>
<th>Project</th>
<th>U-value</th>
<th>U-value</th>
<th>U-value</th>
<th>Salient characteristics</th>
<th>Compactness</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>roof</td>
<td>ground</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>[W/m²K]</td>
<td>[W/m²K]</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Eastura</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
<td>0.53</td>
<td>0.46</td>
</tr>
<tr>
<td>Energy Flex House</td>
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Figure 3. U-values of opaque envelope of the case studies.

A/V ≤ 0.7 m²/m³ is recommended for heating dominated climates due to the fact that a low exposed surface area limits the heat losses, whereas medium-high compactness is more appropriate for heating and cooling dominated climates because the cooling demand is reduced (Wimmers 2012). A high compactness could be sacrificed sometimes in favour of a higher surface oriented to the sun (Passive On 2007). According to table 2 and figure 5, the A/V ratio values of buildings varies between 0.41 and 1.07 m²/m³, indicating high to medium-high compactness.

Figure 5 reveals that, with the exception of Lima (which is a very small, single story building dealing with heating & cooling challenges) and Lighthouse, all buildings exhibit A/V ratios very close or lower than 0.7 m²/m³.

Cooling Loads

In the quest for reduced seasonal cooling loads, passive approaches are divided into three functional component sets: overheating prevention, heat
rejection, and control.

From the prevention point of view, Sunshading, which is critical in preventing overheating in passively heated buildings, is present in all case studies in the form of fixed and/or movable overhangs and/or external screens.

As for heat rejection natural (cross) ventilation is one of the most commonly used strategies to deal with heat rejection by reducing the internal loads in buildings adopting passive design approaches. It is sometimes more effective during the night (night cooling) when outdoor temperatures are lower than indoor temperatures. When coupled to an earth tube system that uses the earth as the cold source, ventilation may also prove useful in reducing the building’s internal loads by pre-cooling ventilation air. The so called ‘stack effect’ is sometimes used to supplement natural (cross) ventilation (by providing building openings and windows at different heights) to increase the passive cooling impact (e.g. Lighthouse).

Information on the use of these various passive strategies in the case studies is summarised in Figure 6.

Second Principle: Energy Efficiency Systems

In order to lower a building’s energy demand, in addition to implementing passive approach strategies, buildings should also rely on improving the energy efficiency of the various incorporated building systems. In the residential sector, most energy consumption is due to systems used to provide district hot water (DHW) and ambient heating and cooling (although in the case study buildings the cooling demand is much smaller than heating in terms of annual energy used). Lighting together with other occupant related electric use, despite not being considered in most building codes, may also play represent a significant amount of the total energy use and its demand should not be ignored in NZEB design.

With respect to the energy efficient systems for ambient heating and cooling, the case study buildings make use of low exergy systems in the form of radiant heating (EnergyFlexHouse, Leafhouse and LIMA) and cooling (LIMA), and efficient mechanical ventilation through air heat recovery (virtually all buildings) (see Figure 6). In addition the case study buildings all include some, or all, of low power lighting, energy efficient electrical equipment and load management systems as strategies for lowering energy demand notwithstanding that their clear advantages are yet to be proved (Musall and Voss 2012). Information on the use of these strategies in the case study buildings is summarised in Figure 6.
Third Principle: Renewable Energy Systems

Having performed all necessary steps towards lowering a building’s energy demand, the last step to be carried out is the integration of renewable systems for energy generation. Since the objective is to reach a net zero energy performance, the lower the energy demand the lower the need for energy generation. In the case of residential buildings with their heating and cooling energy needs, renewable energy systems should either provide the heating and cooling or the fuel necessary to run the space heating and cooling systems together with lighting and other occupant related uses. Consequently the most common strategies make use of photovoltaic systems for electricity generation and solar thermal collectors for DHW production (of the case study buildings only three, Écoterra, Plus Energy Settlement and Plus Energy Houses are not equipped with solar thermal collectors). For space heating and cooling and DHW, geothermal (Écoterra, EnergyFlexHouse, Leafhouse and Riehen) and biomass (Lighthouse) energy sources may also be used depending on the feasibility and the development cost involved. Air source heat pumps, which are used to transfer ambient heat to a useful temperature level, are also appropriate if they meet certain energy-efficiency rating (Lima, Riverdale and Plus Energy Houses). In addition to this, a wide range of combined strategies can be employed. Case Study examples include:

- a building integrated photovoltaic thermal system BIPV/T system able to harvest a large amount of heat (Écoterra),
- geothermal and solar thermal combined with low exergy systems (radiant heating) for space heating (Leafhouse and Riehen);
- buildings equipped with transfer stations (hot water storage tanks) which are connected to a district heating grid fed by a combined heat and power plant fired by wood chips and natural gas (Plus Energy Settlement).

Matrix of design solutions

The main design strategies used in NZEB design have been addressed in the preceding sections in a systematic and goal directed way. Although the role played by each individual strategy remains to be
demonstrated, the representation of the set of PA, EES and RES measures applied in each case in the form of the matrix at Figure 6 offers a more general perspective with several advantages.

Firstly, for each case study it is possible to identify all the sets of strategies applied to the building for each class of challenge (heating, cooling, lighting/appliances/equipment) and each key component of the energy balance (PA, EES and RES). In this way Solution Sets can be established.

Taking the Écoterra building as an example, one can observe that heating challenges have been addressed with PA (high thermal insulation, passive solar gain, thermal mass and thermal storage - 2nd column from the left) combined with EES (heat recovery - 2nd column from the right). The RES applied to answer the same heating challenges are photovoltaic systems (heat recovered from building-in integrated photovoltaics) and a geothermal heat pump (represented in the matrix by the two light coloured boxes overlapping heating challenges).

Secondly, the matrix enables useful insights to be extracted to identify design issues that are more likely to succeed in achieving a true net zero-energy performance in heating and heating & cooling dominated climates. In the context of lowering a building’s energy demand through the implementation of PA and EES Figure 6 reveals that the most frequent strategies rely on high thermal insulation and passive solar gains combined with radiant heating and air heat recovery in the case of heating, and on sunshading and natural cross ventilation combined with radiant cooling and displacement ventilation in the case of cooling.

An interesting aspect to consider in this analysis is the energy performance of the buildings given the respective energy efficiency measures adopted (PA and EES only) (Fig. 1). As it can be seen from figure 1, although neither Écoterra nor Lima have reached net-zero energy performance, they’re both characterised by very low and medium-low annual primary energy consumption, respectively. At the same time, Lighthouse, which can be considered a successful project from the point of view of NZEB performance, exhibits the highest annual primary energy consumption.

Final Remarks

In order to present and discuss the design strategies used in NZEB design, nine projects have been selected from the IEA Task 40/Annex 52 (“Towards Net Zero Energy Solar Buildings”) project database. Although the database indicates that there is no standard approach for designing a Net Zero-Energy Building (as there are many different possible combinations of passive and efficiency measures, utility equipment and on-site energy generation technologies able to achieve the net-zero energy performance), a close inspection of the strategies and indicators of the relative performance of the nine case studies revealed that it is possible to achieve zero-energy performance using well known strategies, a fact which provides evidence in the support of the theory that zero-energy buildings design is a progression of passive sustainable design.

ACKNOWLEDGEMENTS

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Abstract
This paper presents the Latitude Housing System, a speculative model for a means of imagining multi-scalar nested considerations for the development of a mass-customized net energy producing housing system geared to the specific conditions of the Great Lakes region in North America. In the most general sense, the project is motivated by an attempt to frame the discussion of such housing beyond its energy performance alone, and expand by implication, the ways in which we might discuss and debate approaches to the design and delivery of sustainable housing. Considerations that range from regional economic synergies and models of clean-tech collaborations to behaviour shaping building controls systems are presented and briefly outlined as they are applied to a constructed proof of concept prototype, North House, which is based on the Latitude system.

Keywords: Mass Customized Housing, Responsive Envelopes, High Performance Buildings, Net Energy-Positive Housing.

Introduction
There is a long history of architects engaging not only in the design of industrially manufactured housing but also in speculating on the conceptualization and design of the housing industry itself (Rupnik 2012:86-102, Bergdoll and Christensen 2008). However, in the North American context, most of these proposals have, for a variety of reasons, historically failed to achieve the commercial and transformational success imagined by their authors. The past two decades have witnessed a resurgence in interest and exploration of prefabricated housing by the design disciplines, especially as related to the new opportunities availed to both designers and the construction industry by digital design and manufacture technologies (Bergdoll 2008:24). The contemporary context of building design is additionally pressurized by a range of concerns tied to questions of climate change, sustainable practices, and the emergence of ecological paradigms in the design and operations of industrial production. These conditions describe a new context where architectural imagination can contribute to reframing an approach to the challenges of housing delivery.

The Latitude Housing System, a model for speculative mass custom energy positive housing, has been developed by the authors as a framework to recast the role of the house as a high performance industrial product that participates within specific regional economies, that has an impact as part of a broader renewable energy infrastructure network, and that also serves as a platform through which to foster new relationships between inhabitants, buildings and the environment by way of sustainable living practices. The proposal extends beyond the concept of the zero-energy home as an isolated object, pursuing a comprehensive system that aims to address the net impacts of manufacturing, operation, and behavioural transformation in the production of a sustainable society. This paper presents a set of cascading considerations associated with the conceptualization of the system. It also describes a proof of concept prototype home entitled North House, developed between 2008-2010, and currently located in Cambridge, Ontario where it is used as a demonstration and education tool and a "living lab" or testbed for long term occupancy testing and evaluation.

The thinking presented in this paper has been significantly shaped by a number of key texts that in aggregate form a background against which the Latitude Housing System emerges. Joseph Pine’s anticipation and theorization of the ‘experience economy’ as well as ‘mass customization’ fundamentally reframes models for both the evaluation of utility and desire within an information economy, and suggests the development of new models of product delivery that can produce the appearance of the ‘customized’ while delivering the efficiencies of technologically automated production (Pine 1992,1999). Stephen Kieran and James Timberlake’s manifesto Refabricating Architecture...
has been instrumental in outlining the potential of lean manufacturing and mass customized strategies translated from automotive, shipbuilding and aerospace sectors to the building industry and prioritizing its impact on quality relative to cost and time; a challenge that will be critical in the delivery of high performance buildings of the future (Kieran and Timberlake 2003). Perhaps most influential from a conceptual standpoint, however, is the 1944 essay “What is a House?” written by Charles Eames and John Entenza and famously published to anticipate the Case Study House Program. It not only called into question the role of the designer and his or her expertise in working across issues ranging from human behaviour to science and economics, but also presented a complex network of factors surrounding the condition of housing delivery and constituting an ecology of the house (Eames, Entenza, Matter 1944). Similarly, the Latitude project is founded on the conceptualization of a “complex ecology matrix” which serves to unpack and identify the scope and scale of synergistic activities surrounding net energy producing housing in a near future context: from fabrication and delivery to urban planning, infrastructural provision and occupation.

Regional Considerations

In the discussion surrounding the potential for mass-customized net-energy producing housing, it is essential that the breadth of considerations are conceived in terms of cascading scales, by examining the full lifespan of production and delivery, and examining models of emerging industrial and technological development that might be catalyzed through this process. In this way, we can begin to understand the full range of impacts through the multiple lenses of energy, economy and social equity.

The development of the Latitude system aims to address the specific climatic characteristics within the temperate zone of the globe. This zone is characterized in many places by extreme variations in annual temperature, sometimes ranging from -30°C to +30°C, constituting both heating and cooling energy demand. While this zone is also characterized by a reduced number of daylight hours throughout winter months, annual solar irradiation is adequate to produce significant solar resources that can be converted through a range of technologies into both electrical energy and heat, making it possible to deliver net energy positive buildings.

The temperate climate zone also contains a concentration of highly populated, advanced manufacturing cultures. Situated within this zone, the Great Lakes Megaregion (GLM) of North America in particular is home to a confluence of conditions that have the opportunity to expand the implications for mass-customized energy positive housing. The region, rich in both raw material and secondary and tertiary processing supports one of the largest manufacturing bases in the world. With portions of this area currently in decline and seeking repurposing (most significantly, what is known as the “Rust Belt” in the United States), this region already constitutes a site of significant governmental investment in technology transfer to drive the production of new clean tech sectors (White House Press 2010). Latitude is also, in part, a proposal to transform the housing industry through specialized component-based manufacturing processes, aimed at making high performance sustainable housing available to the average homeowner while at the same time stimulating new industries and marketable products. Mass-customization practices utilized in the automotive and aeronautical sectors already present in the region could be translated to the production of housing (permanently or on an as-needed basis), delivering the precision and quality demanded by high performance housing with economic efficiency and integrating principles of design for disassembly and reuse.

This scale and model of industrial transformation is not without precedent. The Japanese ‘system built’ home industry was initiated in the 1950’s to respond to the massive national postwar housing shortage, and by the early 1970’s was steadily delivering high quality product to the market.

Support of the industry’s emergence in the form of economic imperatives and policies, certification, building code modification and prizes have reinforced its growth and reception in the market (Brown 2001). Major corporations have entered the industry utilizing strategies of vertical integration and logistics specialization to produce new markets for existing product streams. Examples include Panahome whose supply chain was organized around the integration of technologies produced by Panasonic, and Sekisui Chemical (1998) whose product lines of adhesives and coatings have added value in the production process (Noguchi 2002, 2003). In a North American context, government financial support aimed at specific clean-tech sectors, and risk distribution between established and emergent corporate partners suggests the potential for a similar model for the delivery of high tech mass customized housing.

The recent partnerships of a company like Guardian Industries provide an example of how existing industrial bases within the Great Lakes Megaregion are already attempting to expand their production lines into high performance building...
Guardian is a manufacturing company headquartered in Auburn Hills, Michigan, specializing in float glass, fabricated glass products, fiberglass insulation and other building materials for automotive and construction applications. In May 2012, Guardian introduced a line of new advanced glazing products at the AIA National Convention in Washington DC called the SunGuard series specifically focused on energy efficiency and energy production. Guardian partnered with Pythagoras Solar Photovoltaics of Israel to develop a glazing unit with integrated photovoltaics that could generate electricity while minimizing the visual impediment of the PV cells. Their partnership with Soladigm Dynamic Glass produced a glazing unit that can dynamically control heat gain and glare through an embedded electrochromic film. To coordinate the integration of power and controls for these systems, Guardian brought in BISEM to manufacture the complete glazing assembly. This type of collaboration between a long-established and broad reaching industrial interest and innovative, relatively young technology companies demonstrates the potential for existing industrial and manufacturing bases to support emerging markets for advanced building products. The mapping of Interlaced Industrial Ecologies (Figure 1) assembles existing regional systems including timber management and processing, float glass production and glazing system manufacture, advanced technology integration, robotics manufacture and architectural and engineering research centres as a multi-layered network well suited to clean-tech application. We anticipate this to be constitutive of both a network of partners that could enable the production model of the Latitude system while also minimizing pre- and post- manufacturing material stream loads due to transportation.

Besides the increased efficiency and economic benefit of coordinating manufacturing at a regional scale, mass customized housing manufacture offers some advantages in terms of greenhouse gas and energy consumption reduction during the construction phase. According to a comparison of the life cycle of a conventional site-built home to a prefabricated modular home, the prefabricated system studied required eight weeks maximum for production, transport, and installation, versus 3-4 months for the stick-frame home, resulting in an overall reduction in transportation time (Kim 2008). Construction materials are delivered in bulk, direct from manufacturers to the prefabricated home construction site, as opposed to having smaller quantities pushed through distributors. Factory-controlled production can also result in less material waste. These factors contribute to a 26% reduction of energy consumed during manufacture and 30% reduction of energy consumed during transportation for the prefabricated home over the site-built home (Kim 2008). The increased quality control that was possible in the factory setting can also increase air tightness and overall energy efficiency. Additional efficiencies to energy use in building operation can be implemented on a production line that would be less feasible for site-built construction. These have compounding impacts as the majority (up to 93%) of a residential building’s life-cycle impact is tied to energy consumption during its operational stage (dependent on expected life span).

While some areas of the GLM are experiencing both economic and population decline, Southern Ontario is notable for its planned population growth (driven almost entirely by immigration) and a recovering housing market, with 67,821 starts in 2011 26,884 of which were single-family homes. If 10% of this market could be tapped to support an emerging net-positive mass-customized housing industry it would represent $960MM in potential gross sales per year. Further,
Ontario’s commitment to developing a significant portion of the provincial energy portfolio through distributed renewable sources is witnessed by both the passing of the Green Energy Act in 2009 and the establishment of the most aggressive feed in tariff program for renewable energy production (Green Energy Act). The Ontario Power Authority’s (OPA) FIT program for large scale renewable energy producers (>10 kWp) has resulted in the installation to date of 1413 MW of land-based wind farms, with an additional 719 MW in development (ISEO 2012), and 242 MW of photovoltaic installations approved (Ontario Ministry of the Environment 2012). OPA’s MicroFIT program for small-scale solar energy producers (<10kWp) offers $0.802/kW with a guaranteed 20-year contract. As compared to an average market cost for electricity of $0.015/kW, this provides a substantial incentive for homeowners to contemplate the inclusion of energy production as part of their home’s potential. The development of a distributed renewable energy network connected via smart grids fundamentally transforms the energy landscape rendering multiple actors, from large corporations to individual homeowners, as energy producers. Advocates of this approach point to the spin-off economic benefits of a transformation in building-linked energy production. Through the introduction of distributed renewable energy production as a fundamental part of building construction, infrastructural budgets are implicated in their delivery, producing 3 to 5 times the number of jobs (and resulting economic benefits) as compared to fossil fuel based energy production models (Kammen et al. 2004).

Latitude System Logics and Design

Latitude is a hybrid prefabricated system of highly engineered modular units and flat packed panels (Figure 2), that enables a wider range of spatial configurations than those delivered via modular systems alone, and also allows for ready adaptation. Core modules contain all plumbing, mechanical and electrical servicing while also providing structural bearing and tortional support for the building via a combination of timber and steel plate construction. Stairs and storage are also housed within the module components producing a rationalized system that reinforces open living space relative to service as a clear planning strategy within unit designs. Individual exterior cladding panels are constructed on a 1.1m ordinance and are comprised of opaque insulated panels, glazed panels,
and hybrid energy harvesting panels. These components aim to deliver a coordinated kit of parts that can be combined to produce a range of spatial types ranging from 80m² to 230m², thereby allowing house configurations to be closely matched to the needs of the inhabitants. The system also allows the houses to grow or for components to be exchanged, updated and recycled at the factory in response to changed familial structures, new technological developments or new climatic or socio-economic challenges.

The design of the houses encourages a connection to the rhythms of the natural world and supports healthy lifestyles: large areas of high performance glazing provide ample year-round daylighting essential for health and well-being (Edwards and Torcelli 2002), operable panels provide natural ventilation and the system includes a series of decks that extend the living space outdoors while providing white reflective surfaces in the winter for increased solar gain with low sun angles. The decks are integrated with raised bed planting for local food production and include components such as greenhouses, extended pantries and exterior storage. All of the home systems are connected through an intelligent user interface designed to sponsor new models of informed inhabitation and awareness in a net-energy producing residential context.

**Envelope System Assemblies**

In order to achieve environmentally responsive envelope performance within the wide range of seasonal climate extremes characteristic of the temperate zone, the design of the envelope components is based on an ecological systems approach, wherein the building skin was composed of performative and interdependent layers that, like the body’s epidermis, are designed to serve individual as well as cumulative environmental functions. The layers are capable of automated modifications in response to external conditions and/or internal demands. Optimized for a broad range of climate variations, this layered, component-based system enables multiple configurations as defined by program needs. Fully gasketed construction joint details allow for ease of servicing, upgrade or replacement of individual components, or whole assembly types.

The opaque building envelope assemblies have been designed with high thermal resistance values, typical of cold-climate, low-energy design. Structural panel assemblies of engineered wood, with offset framing to create a consistently thick assembly with no through-and-through thermal bridges, are used in both vertical and horizontal configurations. Active energy-producing photovoltaic layers are integrated within opaque assem-

![Figure 3. DReSS system layers, as implemented in the North House prototype.](image-url)
The primary glazed assemblies consist of a floor-to-ceiling custom wood frame curtain-wall system with a very high thermal resistance albeit engineered to maximize passive solar gains. The areas of glazing within the houses are maximized in order to connect inhabitants to the outdoors, and to provide for natural light and passive thermal gain in the winter months. Unwanted heating loads are managed by an automated active exterior shading system. Inboard of the primary glass envelope, interior blinds deliver glare and privacy control. The final performance layer of the system is made possible by phase change materials (salt hydrate was used in the first prototype) embedded within the floor’s wood frame assembly to chemically simulate thermal mass: solar heat absorbed throughout the day helps to passively heat the homes and is also stored for use as latent heat throughout the night. This aggregate system we have referred to as the Distributed Responsive System of Skins, or the DReSS (Thün and Velikov 2012) (Figure 3).

Given that summer cooling is largely managed by the exterior shades, the glazing system is designed to provide maximum thermal resistance combined with optimized passive solar heat gain during the winter. Based on extensive energy modelling of multiple iterations, the chosen IGU developed for the first prototype was a Quad-Glazed Krypton filled unit comprised of two 6.5 mm sheets of clear low-iron glass sandwiching two sheets of Heat Mirror 88 mylar films. Low-E coatings on glazing surfaces 3, 5, and 7, with selective transmittance values were engineered to maintain a moderate SHGC across the four-layered assembly. The resulting IGU had a center of glass insulating value of R-12 (U-0.083 W/m²K). The large uninterrupted glass areas minimize locations of edge and mullion incidence and thus the ratio of center of glass (highest resistance) to frame (lowest resistance), resulting in a performance of R-8 (U-0.125 W/m²K) across the whole assembly. The IGUs are positioned within a wood frame curtain-wall system, designed to minimize thermal transfer. The function of natural ventilation is separated from the primary glazing system and achieved through manually operated full-height insulated opaque casement units.

In addition to the component panels that constitute the primary envelope of the Latitude system, a number of active and passive technologies are incorporated into the complete assembly of the unit to enhance the building’s thermal systems. Energy models determined exterior shading could significantly lower the cooling load, while allowing the glazed areas to take full advantage of passive solar radiation during heating months. A Venetian blind type exterior shading system used in the prototype offers two important benefits; (i) the shades can easily and automatically be fully retracted from the face of the building behind its fascia to admit maximum solar penetration, daylight, and views; and (ii) the individual slats are capable of a rotational range of almost 180° allowing for a high...
degree of precision in the control of solar shading. The full height shading panels are divided into two shading zones with individual rotation capacity so that the 900mm high upper clerestory can be opened to allow natural light to enter the space while the lower zone is optimally rotated for blocking solar radiation. Energy modelling indicated that the use of this active shading system on the outside of the house could reduce the cooling load by as much as 46%.

Site Development

A primary issue in the planning of site development and building orientation includes the strategic orientation of units with heavily glazed facades and related energy harvesting systems oriented to the south. In order to optimize density while maintaining solar access, a matrix of plots is designed to facilitate through-block access and produce private outdoor space. The proposed site design displaces shared amenities and parking areas to perimeter laneways, while creating a series of connective paths linking access to individual units. In this configuration, and scaled to the size of an average platting plan densities of 50-60 people per hectare can be achieved, which is consistent with transit oriented development (TOD) targets outlined within planning policy in Southern Ontario for non-central peri-urban locations.

With agglomerations of dwellings the resilience and flexibility of Latitude’s building components becomes increasingly efficient. The houses are designed to be able to be developed as duplexes and townhouses to reduce land use as compared to existing models of detached suburban typologies and to capitalize on the possibility of aggregating renewable energy, waste processing and local food production systems within a market context of single family homes (Figure 4).

North House Prototype

The North House is a proof of concept prototype prefabricated solar powered home that advances the Latitude System as a fully realized testbed (Figure 5). The prototype has been constructed to serve as a public demonstration and education project advancing awareness regarding emerging technologies, solar living and energy conservation as well as to operate as a platform for extensive monitoring, testing and evaluation of these systems, providing the design and construction industry with much needed data for high performance residential buildings. The project was selected as one of twenty finalists in the US Department of Energy’s 2009 Solar Decathlon, where it was visited by over 200,000 members of the public. Design research and construction of the North House Project was undertaken between 2008 and 2010 by an interdisciplinary, inter-institutional team engaging faculty and graduate student architects, mechanical engineers, systems engineers, material scientists, building technologists, software engineers and interactivity designers from the University of Waterloo, Ryerson University, and Simon Fraser University’s School of Interactive Arts and Technology, working collaboratively with professional and industry partners. It has recently been reinstalled at a permanent site in Cambridge, Ontario and we anticipate commencing with performance and occupancy testing in 2013.

As a minimally sized testbed home of 80m², North House consists of a highly insulated core service module to the north opening up to a large flexible living space bounded by high performance DReSS panels to the South, East and West. On the roof of the project, an 8.3 kWp building applied photovoltaic array (BAPV) captures the high summer sun while also integrating solar thermal evacuated tube collectors (4 kWp) for domestic hot water and supplementary space heating. Vertical exterior walls on the northeast and northwest, as well as the south facing fascia, are clad with a glass encapsulated 5.3 kWp building integrated photovoltaic array (BIPV). The active vertical BIPV facades extend the period of daytime electrical power generation, capturing low incidence solar energy typical of early morning, late afternoon, and winter months. This system is anticipated to annually produce up to 6600kWh more than the house consumes (Thün and Velikov 2012). The North House prototype allowed for the opportunity to undertake detailed development and testing of building system components and component assembly logics. It also provided the testbed for the development of two additional components essential to the long-term success of a Net-Zero high performance home: the Central Home Automation Server (CHAS) and the Adaptive Living Interface System (ALIS).

CHAS: Integrated Systems Performance Optimization

CHAS provides measurement, device control and automation that operates the shades and the HVAC system based on exterior weather information and frequently measured interior temperature, relative humidity, and carbon dioxide content, as well as monitoring for the solar electric and thermal pro-
duction systems. During most of the year the house’s heating and cooling needs are met by the exterior shades and the passive building envelope assembly. As this is the more energy efficient strategy, the CHAS privileges this passive method of thermal management whenever possible, reserving the HVAC system as backup. This integrated approach offers significant savings in operational energy as well as capital costs, since the majority of the HVAC equipment can be significantly downsized. The team also developed a customized solar domestic hot water and HVAC system that is estimated to provide an average of 65% of the required hot water for space heating, cooling and domestic uses, with collected solar thermal energy alone. Embedded interior and exterior sensors provide continuous real time data to the CHAS system.

**ALIS: Inhabitant Responsiveness and Energy Conservation**

A sustainable home is more than a green building: it is also a living environment that has the capacity to encourage inhabitants to use fewer resources more effectively while fostering a compelling lived experience. Social scientists have long recognized that the motivations behind energy consumption and conservation are primarily societal and cultural, and have argued that deep social change is necessary to achieving real and lasting energy reduction in the use of buildings. Differences in individual behavior have been shown to produce large variations – in some cases as much as 300% – in energy consumption, even while controlling for differences in housing typology, appliances efficiency, HVAC system composition, and family size (Janda, 2009).

ALIS is a specially designed control architecture and interface that provides the inhabitant with simple, intuitive controls, monitors and provides meaningful feedback on the impacts of their behavior, and also provides inhabitants with social motivation tools to foster sustainable patterns of living. The suite of technologies that constitute ALIS includes an extensive monitoring and data-logging system, three different types of feedback mechanisms (integrated within the home and accessible through web and smartphone applications), and a social network connecting the theoretical community of ALIS users. The monitoring system collects data on energy consumption by use, energy production, hot water and total water consumption, and hot water production, as well as interior and exterior environmental conditions. This information is accessible to the inhabitant via a web application that allows them to view data in many different combinations, at different timescales in breakdowns related to household activities and weather patterns. This system is intended to both educate and support evolving patterns of sustainable human behavior (Velikov et al. 2013).

**Conclusion: Projecting Possible Futures**

In outlining the various and cascading set of concerns, considerations and ambitions of the Latitude Housing System, several questions for consideration emerge that in their very essence, demand a reconsideration of the manner in which we con-
ceive of the house – and in particular, the potential role of net-energy producing housing. The degree of sophistication and integration of technology and material assemblies of such buildings demands a precision of construction, commissioning and craft that can only be delivered by high-tech industrial processes such as mass-customized manufacture. This fundamental transformation in the manner in which housing can be delivered produces a range of potential impacts at a regional scale that include new types of corporate alliances in the high-tech manufacturing and research space and the democratization of energy production and access. Latitude attempts to develop a housing system that is not only tailored in its performance to the specific climate conditions, political and real estate pressures of a region, but as a participant in emerging regional economies.

While the plausibility of implementing such a system has yet to be verified, the cascading synergies described in this initial research suggest a transformation in value that extends regionally in the reduction of infrastructure costs, more compact occupation of serviced lands, and stimulation of emerging technology sectors. It also suggests that the value and cost of such housing may need to be rethought, and that the motivations for its development lie outside of the interests of manufacturer and homeowner alone and possess larger societal value. Quantifying these values, whether accounted for in GHG and CO2 emissions, economic benefit, or in the industrial ecologies of regional manufacturing transformations would constitute a basis for evaluating the impacts of such a system, beyond the conjecture outlined here. Furthermore, the evaluation of the potential for digital and haptic interface tools that transform resident’s awareness and decision making processes with respect to sustainable living patterns, and in particular, those of energy consumption are required in order to assess the long term impacts of such housing types, not only in terms of specific energy performance as utilized, but in terms of their capacity to affect broader behaviours. Expanding the consideration of the breadth and scope of impact and metrics for measurement and evaluation across this set of considerations would enable a more comprehensive approach to the delivery of housing. While the historical failure of such proposals to emerge as culturally significant and substantive in the past is well documented, we may find ourselves at a moment in time, where the manner in which we conceive of larger systems as ecologies, the manner in which we assess outcomes and the means by which we assign value, offers new modes by which to discuss the merits of architecture’s involvement in the conception and design of whole housing delivery systems – and the possibility of such systems themselves.

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CasaZeroEnergy: An Italian Prototype of Zero Energy Building

Antonio Frattari

Abstract
CasaZeroEnergy is the prototype for a building that does not use energy produced from non-renewable sources, but produces its require energy by using alternative energetic systems. Designed according to the principles of bioclimatic architecture, the building was integrated with passive systems for optimizing the site's climatic conditions for heating in winter and for cooling and ventilation in summer. The house was constructed with natural, renewable, recycled and recyclable materials. For this reason it can be classified as a “natural building”. Its main feature is the integration between the building and the alternative systems in order to produce energy from renewable sources: sunspace, solar collectors, photovoltaic panels, a geothermal system and a pellet boiler system. Home automation manages all the mechanical systems to ensure comfort and reduced energy consumption at the same time. The sunspace is a passive solar system used mainly for heating indoor spaces during the winter season. The building’s cooling system is based on natural ventilation strategies and on geothermal heat pumps. The building is provided with shading systems. A smart system was devised to guarantee user safety and security. This kind of system can be controlled remotely and provides constant security for the building.

Keywords: Wooden Building, Bioclimatic Design, Smart House, Zero Energy Building, Renewable Energy.

Introduction
CasaZeroEnergy is located in Udine (Italy). It was constructed from 2007 to 2010 by the company, Gruppo Polo – Le Ville Plus of Cassacco (UD). The main features of the building are:
• Strong natural and bioclimatic features
• Similarity to a passive house concept
• The use of natural, recycling and recycled materials
• A new and innovative anti-seismic timber frame system
• A new and innovative energy-savings envelope
• Low energy consumption
• Integration with energy systems using alternative and clean sources
• Integration with a smart system (home automation) to optimize indoor comfort, energy consumption and security.

Natural and bioclimatic characterization
The natural and bioclimatic behaviour of a building improves indoor comfort, creating harmony with the surrounding environment, enhancing the quality of life. Strong contact of the inhabitants with the nature is facilitated by most of the house’s components, such as the sunspace, the green roof, the large openings, the swimming lake (Fig.1).

The building is in tune with nature, deriving advantages for energy savings, ensuring a more natural life for its residents (Gilijamse 1995). All functional and technical solutions were designed to minimize the use of traditional heating systems, adopting passive design strategies, such as:
• large south-facing openings for solar heat gain; a well-insulated envelope to maintain a comfortable indoor temperature;
• the sunspace, in which solar energy can be stored.

Figure 1. General view of the CasaZeroEnergy.
during the winter, can preheat air used for heating part or all of the building. Furthermore, this buffer space increases usable space. During summer, the sunspace can be opened to avoid overheating. In this way the house is projected towards the exterior and the living room becomes a large open space in direct contact with the garden;

- the swimming lake, reflects into the house the sun rays low on the horizon;
- building orientation, designed for protecting the house from cold winds and optimizing solar gain.

Other passive systems used for natural ventilation and cooling were designed:

- the position of the openings creates a chimney effect to improve ventilation;
- the shading of the windows mitigates heat gain;
- the ventilated and green roofs protect the interior from the hot outdoor environment;
- the sunspace entirely opens the building onto the cool garden enabling outdoor space to enter the interior.

The encounter with nature, for the benefit of the inhabitants’ psychological comfort and pleasure, was conceived in close contact with the surrounding environment and is enhanced by the architectural and technical solution. The building’s north façade is not totally closed (as in a passive house) in order to provide views of the Alps skyline. On the south side is a large terrace and the lake can be used for swimming. A small organic vegetable garden is located on the east side in order to rediscover the traditional taste of vegetables. Deciduous trees are around the building not only protect the house from the summer heat gain and allow heat to enter in the winter, but they also protect the house from indiscreet eyes. (Torcellini, Pless, Deru and Crawley 2008).

The use of natural, renewable and recycled materials

The encounter with the nature is also demonstrated by the environmental protection measures taken during construction through the use of natural, recycled or recyclable materials. Wood and wood-derived materials are used for the envelope and the structure in totally; wood-fibre and cork panels are used for insulation and the structure is in wood.

Several recycled or recyclable materials have been employed for the building components, such as the hardscapes in recycled bricks, the entrance gate in recycled and untreated iron, and the kitchen in recycled glass and aluminium (Fig. 2).

The use of natural materials is also important for the health of the inhabitants. CasaZeroEnergy has noVOC (Volatile Organic Compounds), which means that no dangerous pollutants are in the indoor environment.

In an environmental protection perspective, a strong natural concept was pursued in the design of the swimming pool. It is a natural swimming lake because it only needs partial chemical treatment. Most water purification is carried out by phytoremediation to preserve the natural life cycle of the water (Hernandez 2009).

A new and innovative anti-seismic timber frame system

The use of timber as the main structural material is not merely another natural element, but also improves the house’s anti-seismic behaviour (Fig. 3). The joint between the posts and beams and the bracing system are optimal solutions for guaranteeing safety during and after an earthquake. Seismic energy is dissipated in the reduced movement of the semi-rigid joints.

This is possible only in timber construction,
without the introduction of complex oscillating systems, necessary in steel or reinforced concrete structures. Last but not least, the simplicity of this solution guarantees short construction time that means lower costs and increased safety. A totally Italian-designed frame system produced with industrial technologies was tested. This building system is known as a “dry system” in which all joints are mechanical. The components of the framed systems better adapt to different building forms, even with industrially produced components. Laminated timber, with cross-section of 16 cm at the base and a variable height between 16 and 24 cm, is used for the main and secondary beam structures. They connected to the supporting columns by bolts or rectangular tenons. The roof structure is in glulam timber elements having a section of 8x24 cm², placed with a step of 60 cm, supported by the main beams and connected to them. The finishing is made of wooden matchboards. The horizontal wind bracing is in perforated steel tape nailed to the structure. The vertical wind bracing is in OSB panels having a variable width, depending on the wheelbase of the columns.

**Innovative envelope to save energy**

Particular attention was paid to the energy savings solutions especially regarding the minimization of thermal bridges, the main element that usually causes energy losses. The exterior walls are timber-framed panels with insulation in wood fibre between two plywood slabs.

A continuous layer of cork is outside the panels to guarantee continuity of the exterior envelope, totally eliminating thermal bridges (Fig.4). This constructive solution made it possible to build an envelope with excellent performance both in summer and in winter. The wall's thermal transmittance is 0.22 W/m²K; the roof's thermal transmittance is 0.21 W/m²K.

**Integration with energy systems using alternative and clean sources**

One of the house’s most important features is summed up by the slogan “CasaZeroEnergy” deriving from the fact that the house can be considered as a zero energy building because it has very low energy consumption, does not use any fossil fuel, with an energy demand satisfied by using renewable energy sources. The house complies with the EU directive 31/2010/CE that requires the construction of near zero energy buildings starting from 2020. In particular the energy systems are:

- photovoltaics for 14,6 kWh,
- solar thermal panels for DHW,
- horizontal geothermal plant with water-air heat pump.

The heat pump is integrated with radiant floor heating (Napolitano, Lollini, Avesani and Sparber 2009). This is an innovative heating/cooling system.
based on the criterion that the radiant temperature is one of the most important parameters in achieving the thermal comfort in an indoor space. The water circulating in the floors in winter has a temperature of approximately 33°C - 36°C similar to body temperature. Thus there are no important exchanges between the body and the adjacent space. Therefore, perceiving the temperature of the air, the inhabitants, will be in comfortable conditions. Instead, in summer, the cold water circulates in the pipes with a temperature of approximately 16°C-20°C. Thus the floor temperature is approximately 20°C, causing a thermal interchange between the floor and the human body. In this case the inhabitants will feel cool and will be in comfortable conditions (Hammon, Neugebauer and Shimamoto 2010).

Low energy consumption

The Laboratory of Building Design of the University of Trento (Italy) developed with a mathematic model the prediction of the building behaviour for what concern the energy consumption (Charron and Athienitis 2008). From this model, related to one year, the good behaviour of the building, both in summer and in winter condition, emerged. The considered parameters as base for the estimation were:

- building heated area = 378 m²
- people present in the house = 4
- DHW need = 75 l/person

In particular two different models were simulated. The first one was the model of the house without the sunspace and the second one the model of the whole building, considering the presence of the sunspace. In this way it was possible to estimate the free energy gain coming from this passive solar system.

<table>
<thead>
<tr>
<th>Produced energy</th>
<th>Solar panels</th>
<th>kWh/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photovoltaic panels</td>
<td>20208</td>
<td>kWh/years</td>
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</table>

<table>
<thead>
<tr>
<th>Energy need</th>
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<th>kWh/yr</th>
</tr>
</thead>
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<td>Heating</td>
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<td>kWh/yr</td>
</tr>
<tr>
<td>Cooling</td>
<td>4914</td>
<td>kWh/yr</td>
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</table>

<table>
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<th>COP</th>
<th>kWh/yr</th>
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<td>3385</td>
</tr>
<tr>
<td>EER</td>
<td>2.6</td>
<td>1890</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sold electric energy</th>
<th>Photovoltaic panels</th>
<th>kWh/yr</th>
</tr>
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</table>

Table 1. Geographical (left) versus Relational Proximity (right) of Advanced Producer Services Firms in the Lake Constance Region based on the intensity of network connectivity.

In this first case the house was modelled with only a thermal zone. The results of the estimation are in Table 1.

(DHW = Domestic Hot Water COP = Coefficient of Performance EER = Energy Efficiency Ratio)

From the simulation results it is possible to observe that in one year the house has the possibility to use an high rate of energy produced by itself and save 12930 KWh.

In the second simulation, performed considering the free gains of the sunspace, the model of the house was divided into two different thermal zones: the house and the sunspace. The results of this simulation are shown in Table 2.

In this second estimation it is possible to observe that the sunspace reduces energy needs by 6 kWh/m²year, from 27 to 21 kWh/m²year. The energy saved in one year is 14928 KWh. The behaviour of the house is very interesting regarding energy consumption in both cases, with or without the sunspace.

Surely the presence of the sunspace gives the house a greater possibility for low energy consumption. In quantitative terms, the sunspace contributes 1268 KWh/year.

In order to validate the mathematic model, the building was monitored in real conditions. In particular using 12 temperature sensors in the different rooms, it was possible to confirm the house’s good behaviour. The temperature range in the rooms of the house is constant if compared to the minimum or maximum outside temperature, as can be observed in Figures 5 and 6 below.

As shown in the graph, the behaviour of the house is good because the temperature of all the rooms fluctuates by only 3-4 °C on average both in winter and in summer.

Home Automation

Smart solutions have been implemented in the building for:
testing and verifying the utility and the effective and flexible use automated passive solar systems;
• quantifying the contribution of automated control for lighting, shading and mechanical systems;
• experimenting user safety and security.

The devices and the correspondent functions of the smart system were specifically established in order to manage the interactions of all the technological system components. In particular the following input devices were included in the project for the smart system: temperature and humidity sensors, magnetic contacts to verify opening or closing state of the windows, occupancy and movement detectors and luminance sensors. Each device is connected with a weather station in order to monitor the outdoor climate conditions (temperature, luminance, wind speed, rain). A touch screen makes it possible to visualize and control the parameters available on the connection between the devices.

The building’s sunspace could also be completely automated to help users manage correctly this passive solar system, in order to optimize its contribution. The automation system sends specific signal about correct functioning, based on the outside weather conditions. In this way it is possible to manage the sunspace in the winter or define the total opening in summer (Fig.7).

The implementation of the functional program was previewed in two specific temporal modes: daily and seasonal operations.

The functionalities of the smart system for the sunspace could be:
• automated control of the window opening/closing system in order to optimize convective air flows and the temperature level not only inside the sunspace but also in the adjacent rooms (automated control with priority of manual operation);
• local and remote visualization of the state of window opening/closing and of the sunspace shading system in accordance with the optimal dynamicaly calculated position;
• detection of sunspace temperature values.

The building’s cooling system is based on natural ventilation strategies. The automation system for improving natural ventilation in the interior space focuses on the activation of the windows’ automated opening system. The main input parameter of this function is the local detection of the inside temperature in order to support air flows. The opening system modes are the same as described above for the sunspace.

The building can be provided with shading systems. Their automated control can be applied on different levels of complexity from the simple motorized action of the shading system to the complex control of smart shading systems that can properly change the position of the brise-soleil in according to indoor and outdoor environmental conditions (temperature and light). Thus, by means of the automation control system, it is possible to adjust both the incline (angle of descent) of the brise-soleil elements and their movement speed.

The heating system can be controlled by the automation system. An integrated control of the heating system can be planned. This means that simultaneous use of a radiant heating, solar panels and, eventually, of a high-efficiency pellet boiler (so called “integrated fireplace”) can be possible. The entire system can be regulated with a supervision system using a seasonal mode. It is based on the subdivision of the radiant heating system in thermal zones. The smart functionalities of the control system for this specific application involves the inte-
The integration of the radiant heating with solar panels, the proportional opening of the thermal valves of each zone, the separate and differentiated activation of each defined thermal zone and in addition, the possibility to remotely control the entire system by smartphone.

The photovoltaic panels are connected to the automation system only regarding the data on the hourly production of photovoltaic energy. The comparison of this data in relation with the weather conditions might be useful through the values recorded by the outdoor weather station, correlated with sun position and sky conditions. The smart system can be also included as a tool to guarantee user safety in the house, because it can monitor the domestic environment regarding faults and malfunctions of the systems or fire hazards. Moreover, the automation system could help the normal management of the domestic environment, for example by the automated opening of the heavy shading systems.

The smart systems also enable constant security monitoring of the building, through outdoor detection and alarm systems, accessible by smartphone. At the same time it is possible to visualize visitors’ identity using a video-phone or smartphone. The same magnetic contacts on the windows and occupancy detectors installed for the energy saving management could be used for this function.

**Conclusion**

CasaZeroEnergy in Udine is not only a simple ZEB, but it is also a prototype, with which we want to demonstrate that it is possible to construct a building that can respect the environment in terms of reducing impacts and improving user quality of life. Indeed the goal of the project was not only the construction of a low impact and low energy building, but the construction of a building in which the users’ role and comfort is important. For this reason the design of the building was oriented to ensure contact with the nature, guaranteeing a new and improved quality of life. At present, the first part of the work has been completed: design, simulations and the general monitoring of the house behaviour. Now, we will proceed with more detailed monitoring, to understand energy consumption and behaviour of the single construction components.

**Acknowledgments**

The research project has been possible due to the incessant activity of Loris Clocchiatti, president of Gruppo Polo – Le Ville Plus (Cassacco – Italy), that has hardly longed for the experimentation briefly described in this paper in order to improve the quality of the final product of his firm towards a better and new way of living. The onsite construction of the buildings has been followed by Arch. Carlo Rugo and Geom. Denis Giammarchi. The design of the electric and heating systems has been made by Pldn. Luigi Battista and Pldn. Luca Tomasini. A particular acknowledgments to Dott. Eng. Maria Cristina Grillo for the elaboration of the tables and the graphs.

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Abstract
The world population just passed 7 billion. Fear of growth towards 35 billion, if the “high fertility rate scenario” was maintained, is reduced. The “stable fertility rate scenario” is more likely, stabilising the population around 10 billion in 2050 (Le Monde Diplomatique, 2011). In 1987, as a response to the need for focusing on housing for the lower end of the cost scale, on homelessness, the United Nations chose 1987 to be “Year of Shelter for the Homeless”. An international architectural competition was organized. 123 architects from 44 countries competed in the final (UIA, 1987). Many proposals focused on energy challenges. This paper recoups the UN initiative 25 years ago. It contrasts the challenges of developing countries with those of the developed world, by studying examples from the North European cold climate’s typical mass housing in Norway. One of the examples is from after the Second World War, when in 1948 attempts at building cheap housing was initiated. They met resistance from the establishments of engineers and architects (Hasselknippe, 1982). Another example is from 2012. The paper also studies an example from a South European cooling demanding climate, in France. The aim of the contrasting is to map the progress over the 65 years since 1948, discussing area- and material efficiency as well as methods of reducing costs and achieve a more sustainable mass housing development as signs of an environmental shift of paradigm emerge. Through the comparative analysis, the paper studies combination possibilities between the architecture that is built anyway for the upper cost segment and solutions for the lower cost segment. It explores and discusses if experiences and synergies between them can strengthen both and it proposes a way forward.

Keywords: Sustainability, Mass housing, Homelessness.

Introduction
Homelessness is now emerging in European countries that only few years ago seemed to be booming. Greece, Spain and Italy are examples of struggling economies. Unrest among young people in parts of England has also made alarm bells ring. Youth unemployment around 50 per cent is worrying. Whole families are ending up on the street or as squatters as a result of high dept. If illness strikes, a job is lost or the pension reduced, vulnerable groups suffer. “Out of debt, out of danger”, is a wise saying, but getting there while an escalating price spiral brought housing prices to new heights has proved tricky. Economical accommodation has been hard to find.

Housing costs have been spiralling as a result of new cost driving legislation being introduced. Universal design, energy efficiency measures and the phasing in of renewable energy are such examples. In Europe, the new energy efficiency directives (EU, 2010) and the push towards Net Zero Energy Buildings will drive up building costs by five to ten per cent for homebuyers (IEA, 2008). The long-term consequence, though, is positive in that it ensures extremely low energy running costs.

A North European case from 1948.
After the Second World War (1940-1945) the need for affordable homes was imminent. Yet there was a tendency to carry on building with the same time consuming and costly techniques as earlier. They did not respond to the new needs for cheap housing arising when rebuilding the bombed out European housing stock.

However, in Norway after 1945, through the low cost housing of the entrepreneur Olav Selvaag, signs of innovation appeared, but created debate (Selvaag, 2012). Even before the war, he had claimed that he could build three times as many houses with the available workforce and money as the government expected. He reasoned that the country could simply not afford to build as expensive housing as it did before. If it did, it would be impossible to house everybody. He argued for a change of policy whereby more and cheaper dwellings were built (Hasselknippe, 1982:10).
only condition Selvaag set was that the authorities should relax the building regulations by allowing him to build slimmer constructions using 3” (75mm) American timber frame construction. This offered a u-value of 0.3 – 0.4 W/m²K, which was an improvement. Compared to the bulky concrete buildings of the time, this was slim. “Wasting materials the way the building regulations force us to do, should be a punishable offence”, he argued (Hasselknippe, 1982:13) and questioned the logic of the building regulations.

The architectural and engineering establishment challenged him to prove his case through documentation and calculations and he offered it for their perusal.

One of his critics was Professor Holmgren from NTH, now the Technical University NTNU. He was engaged by the building authorities to evaluate the proposed Selvaag construction and concluded that the calculations were misleading. The performance of the house from an insulation point of view would not be as designed. Selvaag felt this was an under-the-belt attack since he had documented that the house would have twice the insulation level prescribed by the building regulations at the time (Hasselknippe, 1982:33-34).

A proposal to expel Selvaag from the Norwegian Association of Engineers emerged because established research institutes were claiming that the house could not stand up. Selvaag was challenged to document his ideas in full scale when the newspaper Morgenposten put up the money to build a prototype. He finally got permission to build a demonstration house. It was completed during September 1948 and 8 221 buyers registered. Selvaag had claimed that he could build cheaper than anyone and for less than NOK 16 000 (Euros 2 000), including foundations but not site cost. The 72m² house had three bedrooms. He managed to deliver it ten per cent below the estimated cost. Imagine what could be done if he rationalised the building process further. I

The demonstration proved that he could actually build three times as many units as the government-supported establishment managed for the same amount (Fig. 1).

The prototype sparked interest all over Europe, but in Norway there was a tight link between the Governing Labour party, whose policies Selvaag had criticised, and the NRK, the State funded Norwegian Broadcasting Corporation. NRK was stuck in a misunderstood Government loyalty or neutrality. Selvaag was hardly offered a microphone there, while BBC in London broadcasted repeatedly. During the opening week NRK produced only one report from the occasion. BBC sent a building journalist that produced three full programs about the remarkable house (Hasselknippe, 1982:30).

The whole fight had been about housing the poor. It was a fight over building methods, of whether to go for a heavy expensive “Rolls Royce” or a light economical “Volkswagen”. It is a universal issue even today and all about either choosing rational construction methods for the many or extravagant ones for the few. Now - 65 years later - the house still stands. It made the architectural and engineering establishment at the time the laughing stock, since the house later became a model for how most housing in Norway was built from 1951 onwards.

The story of how Selvaag fought to become the housing supplier for the poorest and war strucken in Norway, was the beginning of a revolutionary mass-housing era. In spite of the authorities finally realising that Selvaag was right, he never received a public apology. Selvaag’s affordable mass customized housing was based on a very simple analysis: He reasoned that it was the use of too many, too bulky, too costly materials that brought the costs up. Houses where designed from over-dimensioned constructions based on unnecessary safety
measures. In some ways this is a parallel to the authorities’ drive today towards bulky 400-500 mm thick walled Passive houses practically eliminating envelope heat losses.

Selvaag was a down-to-earth engineer who tried out things in full scale. He had built a lot of housing before he even presented his famous claim. “Light weight” or “material saving” housing became favoured by the Housing Directorate in order to increase the number of new units. The building regulations were later adapted to fit Selvaag’s ideas. The Selvaag story is a story of endurance and sustainability, about developing rational area efficient plans, about using just the right amount of materials and avoiding waste as well as choosing the right sequence of construction. Selvaag’s achievements sparked a new housing interest and a range of entrepreneurs entered the growing market. But soon the downside of mass production became visible as architectural qualities vanished. Variation and local adaptation disappeared. As time went by the need for more individual expressions designed for each homeowner arose. The concept of mass customization was established as a combination of mass production and individual customization. At the time this was a revolutionary concept and Alvin Toffler anticipated it in his book “Future Shock” (Toffler, 1970). Stanley Davis coined the term itself in 1987 in his book entitled “Future Perfect”, while in 1993 Joseph B. Pine II eventually systematised the general methods of mass customization. Noguchi and Friedman in their paper later established a design system model based on the Japanese prefabrication industry (Noguchi, 2002).

The North European case revisited 2012

The learning outcomes of the 1948 Selvaag case were:

• The establishment will often defend established truths.
• Questioning cemented truths can lead to improvements.

In this light, it is perhaps “normal” that as decades pass, new borders must be passed and memories of former “battles” are forgotten. Today history repeats itself. Architects are again criticizing the Selvaag Group (Dokk, 2012) for aesthetic reasons for building for the low cost end of the market, in spite of the fact that they do this to deliver socially-, economically- and sustainable homes for the low-income groups. Selvaag tries to find a balance between targeting low enough cost levels to allow young people accessing the housing market through offering acceptable housing- and landscape conditions for people. It is a balancing act.

No city is satisfied with a high cost policy. A good city strikes a balance between housing the masses in an affordable way, while offering landscape qualities to all. This is the balance Selvaag fought since the Second World War. It is a fight all urban planners tentatively would be expected to be participating in.

There are shrinking cities and growing cities. There are relatively new towns and older existing towns that hardly change. They all call for different approaches as they contain different inherent challenges. It is clear that we cannot all live in garden cities (Howard, 1945). The challenge facing growing cities is how to condense while ensuring a high quality environment. Many planners and architects respond by offering high-quality designs. The recent literature is reflecting this (Scott, 2012:237-256). It is crucial that this on-going discussion is stimulated.

The UN Year of Shelter for the Homeless case 1987

The UN declared 1987 the “International Year of Shelter for the Homeless”. The homeless drama was to be highlighted and solutions sought. Among the tools applied was an international architectural design competition. Architects were invited to propose solutions on a global scale or a local site-specific one. The competition focused on new technologies for social housing in developing and developed countries. Some focused on the environmental side of the challenge, searching for untraditional solutions to the housing problem with energy issues at the core (Røstvik, 1992:128-129).

A lot of good ideas emerged, showing how to design and build affordable mass housing with low running costs, while maintaining a high level as regards sustainability. The materials used, the travelled distance and the energy sources used during the life span of the building matters in relation to climate gas emissions but also has an impact on the individual’s economy. If local, renewable energy can be supplied as an affordable commodity ensuring low running costs, it could become the preferred solution in many instances. The winning projects and the honorary mentions were gathered in a book and printed (UIA, 1987).

Several proposals looked at the fact that people themselves do not initiate the majority of housing construction in the world. Developers do. Many developers make more money from large
expensive flats than inexpensive small ones. The profit margins are bigger on the large flats. One way of controlling the developers and avoid this is through building authorities forcing them, as a condition for issuing planning permission, to build some small low-cost flats at a limited cost level set. If 25 per cent of the flats in a development are such non-speculative small flats, the developer can do whatever he likes with the remaining 75 per cent. The rich thus subsidizes the poorer, or at least guarantee that there are smaller and cheaper flats entering the market. Such smaller flats do not have to exceed 25m².

Further down on the poverty line of the housing market, an approach as to ensuring low costs could include the components described in one of the projects (UIA, 1987:24-25).

1. A step-by-step process to develop housing over time, through a considerable labour input from the owner.

2. A policy of using local labour and local materials to bring down transport costs.

3. A policy of area efficiency ensuring a size that fits the user’s needs and avoids waste of space and money.

The competition’s winning entries were supposed to be built by individual governments in the winners’ home countries. This did not happen and they remain mostly published in the literature only (Fig. 2.)

Another winning project that could be applicable even in New York’s Times Square or any other mega city’s centre, pointed at a universal solution, that of using the one metre wide available space between a building’s wall and the large and often electric lit advertising board. This space between the private and the public and the question of who owns it, was at the core of the proposal. By making the “in between” space accessible through stairs and by slight improvements of the “scaffolding” already in place to hold the board, homeless could climb up to find shelter from rain and snow. If wind protected, the small space could be slightly heated by hence wasted heating energy from the electric lights. This particular proposal called for
legislation ensuring that all such boards were equipped with proper spaces for the homeless, offering exact dimensioning (UIA, 1987:14-15). The proposal was named the “The thick-ad Law” (Fig. 3). In addition to encouraging the use of existing boards’ rear sides, it announced: “From 1988 all advertising shields in the cities are to be “thick” enough to be used as a modest shelter for homeless. 3m² area will equal one shelter for a homeless.”

A complete rethink of how we build, who builds, under which control and conditions seems necessary to ensure innovative ways of housing the poor. It is a challenge encompassing not only the obvious technical-, cost- and ownership model issues, but also environmental qualities as used in the term sustainability leading the thoughts towards energy and pollution (Lee, 2011). To a certain degree, it is a matter of aesthetics as well (Lee, 2011:168-178).

**Compact housing size as an environmental initiative.**

Le Corbusier, in his book The Radiant City (Corbusier, 1935), argued for an open and green design approach stacking people in compact flats on top of each other instead of dispersing them all over the ground like the British Garden City approach did. He designed flats that he argued would be rational dwelling machines offering people 15m² per person. Although this is a long time ago, the challenge remains.
Le Corbusier practiced what he preached. In the private little cabin he designed at Cap Martin, South of France, he and his wife spent all the summers since 1952, until his death in 1965. They stayed in a compact, rational in every detail, timber construction of 16 m² occupying only 8 m² each. (Røstvik, 2007:38-42)

Le Corbusier was at times hammered for his brute use of concrete. Yet in his own timber cottage he showed how mild he could be (Fig.4). He was fighting escalating costs and his remedy was to build compact and rational housing schemes.

Decades after his death, towards the end of the century, a trend towards fighting rising housing costs for students saw designs where a similar rational approach was applied, that of using retired steel shipping containers as a module stacking them on top of each other, connecting them with bridges and stairs (Helsel, 2001). Several such projects emerged and argued for a new life for retired steel shipping containers (McLean, 2008). They were given the nickname “Future Shacks”. Their compactness, sustainability driven recyclability, low cost and module based character inspired architects in many countries to search for less material- and manpower demanding production methods for housing. This was exactly what Selvaag attempted sixty years earlier (Smith, 2006).

Compact sustainable mass housing to combat a “no-hope-future” mentality

The financial turmoil in many European countries is now leading to compressed family dwelling patterns. Many young people have moved home to their parents in order to deal with lack of income. In countries with youth unemployment around 50 per cent, it is crucial to offer hope to inhibit a “no-hope-future” mentality from spreading. This can be done through the rethinking of the design of the minimum need housing unit, a unit of bare necessity, as a start up unit. A unit that is based on bank loans from institutions with patience, offering the young to take the time necessary to work themselves out of the crisis. This is not possible as long as contractors keep building speculative housing based on a size and cost level that only the affluent can afford, while the hardest hit, the youngest, remain in the hands of the impatient bankers.

In other countries with a more – for the time being - booming economy, similar challenges occur. Soaring housing prices resulting from increased site and construction costs as well as developer profits, have resulted in the involvement from parents having to guarantee for loans. Norway is an example. As a result, a two-class system has emerged; those that have parents that can help and those that don’t. This division is unhealthy and in a social democratic nation like Norway where more or less the same party (Labour) has been in power apart from shorter breaks and with or without partners since the Second World War, the situation is remarkable. In a super rich and oil exporting economy, how can a two-class system emerge when there is practically no unemployment, only 2-3 per cent?

The image of a flourishing oil economy is confirmed by an all-European study mapping where it is easiest to find work for architects. Norway is the country where it is easiest (Archdaily, 2012). How then can a society practically without unemployment “refuse” its youth to enter the housing market? It can, because soaring costs have resulted in m² costs for flats from Euros 3 000 to 10 000 depending on location. Per unit housing costs are also soaring, because with all kinds of facilities included, the standards are increasing. As a result, the debt level of Norwegian households has increased by 50 per cent during one decade only (2002-2012). Area use per person has also been rising steadily along with growing affluence, especially between 1967 and 2000 (Table 1) (Nordby/Miller, 2010).

You may think; how do the above examples relate to the UN Shelter projects whose main grasp was to look for ways of economize on material use, area use and to establish a step-by-step building process? How does it relate to the Selvaag case?

Selvaag’s main grasp from 1948 was done at a time where land area was abundantly available and cheap. Detached housing was the model. His main approach to bring costs down was a sustainability measure. He argued for more efficient use of materials and for compactness, area efficiency. He offered people work on the house to reduce costs.

The Selvaag Group’s grasp today is still to condense cities. This is also a matter of rational area use. As a consequence, the company runs up against the challenge of quality in the spaces
between buildings, leading to reactions from many urban planners. The tremendous pressure on inner cities must be addressed, instead of dreaming of a long gone time where scattered detached housing and luxury apartments set in a green landscape dominated cities. Condensing has its drawbacks but also advantages - not least that of reducing the eco-footprint per capita. Allowing more people to be walking or biking to work or to school, eliminating the need for a personal vehicle, is a valuable idea that has to be developed and protected. Contradicting this is new research indicating that if people move from detached housing to rather sterile apartments buildings, many miss their gardens so much that they will want to travel more often than before to greener spots, often abroad and hence increase their carbon footprint by a travel intensive lifestyle.

A comparative analysis

Is it possible then, through a comparative analysis, to study combination possibilities between the architecture that is built anyway for the rich and that of the lower economic segment, as in the 75/25 per cent example? Can experiences gained in either case create synergies? The UIA Shelter for the Homeless competition showed that this is possible. Several proposals showed designs where one by inexpensive initiatives and a moderate use of materials could house the poor at an affordable cost. This is good news because to approach, address and solve the challenges of the homeless, will lead to better and safer cities.

This paper has been searching for signs of a shift of paradigm as regards sustainability. What kinds of solutions are sought? Are they technical or architectural? The findings are indicating that, while until now, a lot of effort has been put into developing a range of energy efficiency technologies and renewable energy systems that have a cost-impact on the investment but leading to low running costs, Building larger and larger units calculated in m² per person happens while there is a push towards zero energy (Voss/Musall, 2011) and plus energy buildings. Such a push do however seem to ignore one key factor, the one represented by size. Is area efficiency ignored? It takes almost twice the energy to power twice the size of a building. Logically, one would have thought that there is a great drive towards designing more compact housing units. This is rarely the case. On the other hand, as a result of financial crisis in some countries people are getting to live more densely as young people are forced home to their parents. This is not a healthy development as it is not voluntary. However, the ecological consequences might be positive, as it leads to a more compact dwelling pattern.

Compressing the lived in space is one of the cheapest way to save costs. The ideal goal for a suffering economy could tilt towards 15m² per person rather than towards 60 m² per person, as seen in Norway. It is no doubt fair to question whether 60m² per person will be ecologically and financially sustainable in the future and whether it is ethical.

Conclusions

The technological development is fast and accelerating. Most people are hence barely able to understand and adapt to recently emerging innovations. While the focus on mass customized housing so far has been on energy efficiency, characterized by extreme increases in insulation levels on building’s envelopes and the introduction of innovative renewable energy and other technologies, simple non-technology based planning measures have been played down. A revival of those could encourage a redirection towards area efficiency by questioning what is really needed of a well functioning bare-necessity unit. This could lead to lighter constructions, less material use and a reduced ecological footprint. It seems necessary to re-establish sustainability as a key parameter in the mass customized housing market, without adding costs and burdens to the first time home buyers.

In order to deliver affordable and sustainable homes, a study of good examples is necessary. It is a paradox that several of the most relevant examples are found in the low cost end of the market; squatter projects as well as in the work of Le Corbusier and Selvaag decades ago. Those projects, with a goal of offering excellent accommodation of 8m² to 15m² per person are still well worth studying, along with today’s designs of inexpensive retired shipping containers used as student accommodation of 20m² or less per unit. Such projects show many ways of achieving area efficiency. Most probably there are more to come as new challenges spark innovation.

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MODULAR, SUSTAINABLE AND CUSTOMIZED: PROJECTS FOR THE CONTEMPORARY DWELLING

Alessandra De Cesaris & Domizia Mandolesi

Abstract
The home is the place where the intimacy of living is manifested and where relationships with the outside world are formed. The truest sense of domestic space is expressed in the opposition between the interior dimension and collective aspirations. A society’s needs and aspirations are reflected in the transformations of the dwelling, the city’s basic unit and constituent element. The history of the dwelling can be read as the history of the relationship between the desire for the self-representation of an interior world and the desire for identification and recognition within a community. These considerations lie at the heart of the research conducted by HousingLab - DiAP - Sapienza of Rome with the goal of developing low-cost residential projects that can be customized and tailored to individual needs. To meet the demands of a large and heterogeneous public, these projects must refer to industrial processes for the manufacturing of mass-produced goods. But how is it possible to reconcile industrialization and mass production with the need for individual expression or with the desire to freely give form to a home, modify it, and define its character according to individual tastes and its physical context? The goal is to create a catalogue of a system of a limited number of easy-to-assemble, standardized and prefabricated components that can generate controlled, but extremely varied and flexible, configurations of domestic space in order to accommodate different needs in relationship to individual taste and different locations. This article will present a series of projects designed by HousingLab - DiAP - Sapienza of Rome highlighting the relationship between architectural quality, energy use, environmental and economic sustainability, and innovation.

Keywords: Customisation, Housing, Quality Production, User Participation, Sustainable Development, Prefabrication.

Introduction
The accelerated growth of urban fringes in recent years calls for a comprehensive analysis of methods and strategies that can be deployed in such areas. However, it is necessary to take several issues into account, such as: the characterization of the new urban landscape and its sustainability, the relationships between outlying urban areas and the existing city, the influence of urban transformations, changes in lifestyles and residential design. Housing design in the fringe areas of the contemporary city is a critical topic in architectural research today. Changes in contemporary lifestyles, as highlighted by Marta Calzolaretti (Calzolaretti 2009: 11-43), require substantial changes in housing design both on the urban and building scales, starting from the research on housing and building type that has remained suspended for many years. As in other countries, in Italy the change in the composition of the family unit, immigration and an aging population, together with new employment dynamics, such as job insecurity and the nomadism of youth, are modifying housing needs. Moreover, the concept of sustainability is shifting the focus of housing and urban design to the environmental, social and economic dimensions. We maintain that only an integrated approach to such issues can change space and use in contemporary housing. The housing projects presented in this paper are based on the study of settlement and building types that can respond to new social needs. These studies were conducted by HousingLab - DiAP - Sapienza of Rome and constitute the experimental phase of our research which seeks to define design criteria for new residential building projects in urban fringe areas. The design criteria are based on the assumption that new settlements should seek social, economic and environmental sustainability on all project scales, from the plan to the aggregation of buildings to the organization of residential units to the use of technologies and materials.

Based on these considerations, four significant issues emerged. The first regards the design of housing that is not self-contained but integrated with the existing context. New systems for public space, services and housing can create networks within an urban area to enhance its potential and at the same time enable different kinds of social life. The second concerns relationships between new
construction and the urban and natural landscape that defy today’s formal and linguistic homologation. The third aspect concerns the need to design multiple solutions that allow variations and flexibility to create urban configurations suited for a variety of users. The final aspect concerns renewed attention to prefabrication, particularly the need to reduce energy consumption and increase manufacturing efficiency by applying industrial approaches to building production, similar to other manufacturing sectors.

**Building type and dwelling unit**

Innovating the organization of buildings by taking into account inhabitants’ environmental and living conditions is an important tool for improving the quality of the urban environment and the life of its population. Housing that seek to meet today’s diversified and ever-changing social demand should provide a great variety in terms of:

- type and size, enabling the variation of interior space and dimensions;
- long-term flexibility, allowing the recombination and division of divide dwelling units;
- a system to accommodate small volumetric increases.

Lastly, one of the essential aspects that should be considered during the design phase is the potential for customization to accommodate different tastes and lifestyles.

**Housing and customization**

One of the main issues in contemporary residential design regards sustainable and low-cost solutions for housing with formal and environmental qualities that can be customized and tailored to individual needs. To meet the demands of a large and heterogeneous public, these projects must refer to mass production process similar to those used for airplanes, cars, and other design objects. In fact, prefabrication reduces waste of raw materials through the exact computation of the materials needed for the production of a given object. Recycling is easier than on-site building, and the constant search to improve the quality of each component guarantees a building’s performance especially in terms of energy consumption. Finally, as highlighted by Matteo Zambelli (Zambelli 2011: 4-29), producing a building in a factory and constructing it on site in a short period of time reduces the impact of the construction site itself with its well-known risks of acoustic and environmental pollution and the hazards associated with building equipment. But how to reconcile industrialization and mass production with the need for individual expression or with the desire to freely give form to a home, modify it and define its character according to individual taste and the environmental and urban context? Naturally, the idea of the home as an industrial product must be accepted by future inhabitants. To overcome this problem, prefabricators are seeking architectural experimentation. The projects illustrated here demonstrate the existence of a poetic that involves the organisation of plans and volumes of the modular and prefabricated dwelling.

**The custom-made home. “Living box”, 2005**

One of the topics of research conducted by Housing Lab, as we have just said, is the development of low cost housing projects with formal and environmental qualities that can be customized and tailored to individual needs. “Living box” responds to the need to personalize the home by developing a basic kit of easily-transportable, pre-assembled, industrially produced units that can be combined on site. The main goal is to create housing with a limited number of standardized and easy-to-assemble prefabricated components that can be chosen from a catalogue to generate controlled spatial configurations of the domestic environment. These components should be flexible enough to respond to different needs in terms of personal taste and in terms of adapting to differing local conditions. The low-cost and flexible “custom-made home” is conceived for a broad social strata, encouraging self-construction and user-defined domestic space. Potential applications could be in the tourism sector or for temporary, private vacation homes. Use could be made to provide social housing solutions for the neediest or in case of natural calamities. The basic unit is a prefabricated square “box” composed of wooden frames whose overall length is 3.00 meters. The layout and number of sides that can be opened with respect to fixed floor and roof allow different configurations of the basic unit and of the dwelling’s structure. The use of wood is suggested because of its relatively low cost, lightness and reversibility although the “box” can be made with other materials having similar characteristics. The basic “box” is a container of components that can be assembled on site. Its limited dimensions also allow the transportation of up to a maximum of 3 elements per vehicle. The basic units are positioned in a precise sequence to obtain the desired configuration. Once they are opened, the other
components are assembled inside. The floor is mounted before opening the basic units to guarantee stability. Once the bearing structure is mounted, other components can be assembled. Only one person is needed to set up the structure. The combination of basic units, from two to three “boxes” per vehicle, provides different dwelling types, having a maximum height of two stories. Simplicity and versatility allow an extremely simple and rapid reconfiguration of domestic space by increasing or decreasing the number of units according to the needs of the family unit. Various urban forms can be generated by the different combinations from the single family home to simple rows or courtyards to mixed schemes forming more complex urban forms. The preassembled components of the basic “box” are: frames, bracing and interior partitions, ground floor and roof. The wood structure focuses on the use of natural, non-polluting and reusable materials with high thermal inertia. Solar roof panels and ventilated façades for exterior walls are integrated with the design. Components can be chosen and assembled on the site: exterior fittings, interior fittings and flooring, glazing, roofing, walls equipped for sanitary fixtures. These components can be chosen from a catalogue together with the basic unit to create a complete kit that is ready to assemble upon arrival at destination (Fig. 1).

![Figure 1. living box: International Design Competition “The custom-made home - Living Box”, Italy, 2005. Project by Domizia Mandolesi (HousingLab - DiAP - Sapienza of Rome), Pina Colamarino.](image-url)

The home-of-the-future competition promoted by IKEA, as we said on a previous publication (De Cesaris 2009: 61-78), provided the opportunity to experiment the potential of a house intended as a ready-to-assemble kit. This is not a new topic in the history of architecture. Many architects have faced with the issue of designing industrially produced dwellings as Le Corbusier with “Maison Citrohan”, the house that would be serially produced like automobiles and Wright with “Assembled House” (1931), a house based on three minimal units that could be enlarged as required by user’s needs. In the 1940s, Wachsmann and Gropius - who had migrated from Germany - designed the “Packaged House” for the American market; it was a single storey dwelling with a straightforward rectangular plan, a lightweight pitched roof and a porch. But the project was a true failure. For Wachsmann (Wachsmann 1995), as Colin Davies says (Davies 2005), the Packaged House was not really a house, not a place for the lives of real people and not even a machine for living; it was an abstract geometrical system tending towards mathematical perfection. Buckminster Fuller designed “Wichita House” as a hybrid version of two prototypes that were never assembled. Built by William Graham in 1948, it was one of the most innovative single-family houses. Like Dymaxion “Wichita House” (Neder 2008) would enter the annals of replicable utopian homes. Like Dymaxion “Wichita House” (Neder 2008) would enter the annals of replicable utopian homes that would never see the light of day. In 1945, John Entenza, the editor of Arts and Architecture magazine, launched the “Case Study House Program” and commissioned various architects to design mass-produced dwellings. Among these is Ray and Charles Eames’ (Kirkham 1998) “Case Study House 8” which became their own home and studio but was never included in a catalogue. The Maison Coque proposed to Citroën by Jean Prouvé (Ellis 1985: 46-51) in the early Fifties was considered too innovative. The House for the Abbé Pierre by Jean Prouvé, 1956 (Prouvé 1971), as well “Case Study House 8” was built as a single prototype and was never mass produced. The load bearing structure containing services placed in the center of the living room was probably considered too radical a solution. None of these, and other examples ever went past the prototype stage. Colin Davies (claimed that no designer was really determined to build such houses. “With the possible exception of Frank Lloyd Wright’s Usonians, all of the above houses were designed with serious intention of putting them into mass production.” Nonetheless, a market demand did exist. Buying houses from a catalogue during the early years of the twentieth century in the United States was a rather common practice (Di Michele 2002). Several companies offered mail-order homes, the most important of which was Sears Roebuck. Between 1908 and 1945, Sears produced more than 450 different house types and sold about 70,000 units without any input from famous architects. Even in Europe, prefabricated timber houses were built in the suburbs of several cities between the 1920 and 1930. Lastly, in 1996 IKEA started to produce houses for the Swedish and British market to meet the desperate need for low-cost housing in those countries.

As the examples we have just described, the Housing Lab - Sapienza proposal is based on the aggregation of modules that can be selected from a catalogue and assembled according to several extensible and variable configurations. The modules are designed to be manufactured off-site, transported to the site by truck, and dry-built in a very short time frame. The specific design of each module is determined by functional and bioclimatic needs. Indeed, the house can provide its own energy balance thanks to a passive solar heat-gain system connected to an active solar system. There are several types of modules: a service module with bathroom, kitchen, laundry room, wardrobe and stairs; a circulation module which is the tallest element and works as a solar collector; a wired module with connections to the data communications network room. Two modules can create different configurations of living room, dining room, bedroom and office, greenhouse, and water storage tank. The smallest dwelling (28.00m²) is composed of 6 modules. The modules should be mounted along the North/South axis in order to best exploit available natural resources (sun and wind). Starting from the basic unit, it is possible to create a varying number of configurations that can meet the needs for personalization, flexibility and adaptability (Fig.2).

New Italian social housing.
“Cohousing at Fidenza.” 2005

The “La Nuova Casa Popolare Italiana” competition with its explicit request for non-conventional solutions offered HousingLab the opportunity to investigate the potential of soft forms of co-housing to satisfy new contemporary needs. One-family households are no longer the only social group that require housing. New subjects are currently stimulating the market which has not yet adjusted to the changes under way. In Italy, there are approximately six million singles that might not remain so in the future. Furthermore they have friends, lovers, chil-
Children from previous marriages to accommodate and therefore require flexible dwellings that can be adapted to different needs. Even among young couples and people over fifty, there are those who prefer to share space and services that offer economic savings and an opportunity for social encounters and cohesion. Furthermore, temporary dwellings with shared services that can simplify daily routines are becoming indispensable due to the ever-increasing number of relocations for economic reasons. Shared living—without hippie-like nostalgia for the 1960s—today appears to be a possible sustainability strategy.

The Housing Lab proposal consists of an aggregation of minimal units that guarantee a more private dimension clustered around communal areas. Individual space is composed of a 20/27-square meter minimal living unit that contains several functional areas: bathroom, closet/wardrobe, bed, TV room/office. Another 1.50-sqm-wide balcony space can be enclosed and used for different purposes. Multiple living units aggregate around communal spaces and form dwellings of various dimensions. Two possible ways
to aggregate the units were explored. The first is a horizontal configuration in which the units constitute aggregated independent units, each having a separate entrance and consisting of two levels. Vertical aggregation comprises four stories, in which three minimal units on the ground floor are grouped around the common area. A flight of stairs and an elevator give access to a roof shaded by photovoltaic panels. Based on climatic analysis, it was found that 5 months are considered extremely cold, 2 fairly cold, 3 comfortable and 2 hot, and that winds are practically non-existent throughout the year. In winter therefore, solar power can provide a significant contribution to the buildings’ energy requirements. To this purpose, the following systems were designed: solar energy collection, heat storage, and distribution. In summer, the goal was to facilitate natural ventilation and heat removal by means of solar pipes and blocks, which work as heat accumulators during the winter and also serve to release hot air. The units are built with AS-Holzbau system wood boards. Energy sustainability is guaranteed by the photovoltaic panels on the roof which are used as a pergola on the terrace of the tallest building (total area: 252m²) (Fig.3).
New social housing model. “Fano solidale.” 2009

The social and economic changes that have come about in the last decade have re-kindled debate and research on housing. Meeting a complex and variegated housing demand, as we asserted on a previous publication (Mandolesi 2009: 79-95), requires targeted strategies in relation to which some issues are priorities that can no longer be postponed. Privileging the development of social housing constitutes one of the most critical aspects for many of our urban contexts. Re-thinking the relationship between the private and the public realms in order to create a shared living dimension in light of new demands brought about by immigration and globalization is tantamount to reconsidering the relationship between building types and urban fabric. Pursuing the economic and environmental sustainability of housing also implies an overall reconsideration of urban and architectural choices, construction processes and systems and ways of using the dwelling unit and the entire neighbourhood. Finally, thinking about the human and symbolic implications of a home, searching for models that can reconcile individual needs and community life in a public, shared and participated dimension mean facing issues of identity and flexibility of domestic space as well as thinking about the “elements of a gradual filter between public and private” – open spaces, green areas, circulation corridors, business places, etc. – which are a fundamental and inevitable part of housing design.

The project for low-cost housing and services in San Lazzaro, a fringe area in the city of Fano, is based on these theoretical considerations. Since the project represents a meaningful opportunity for defining new housing models, the system of voids and public spaces in which different dimensions and characteristics alternate with building volumes becomes the backbone for the new layout. The goal is to define a neighbourhood centre characterized by multiple functions, a place that can offer different opportunities and a better quality of

Figure 4. Fano: Design Competition for Social Housing at Fano, Italy, 2009. Project by Domizia Mandolesi, Marta Calzolaretti (Housing Lab - DiAP - Sapienza of Rome) with D. Cartagna, L. De Vincenti, A. Felici. Second Prize.
life with places suitable for children, youth, the elderly, and families. To achieve these goals, the structuring spine of the new urban design is incorporated within an ample pedestrian promenade that diagonally crosses the area. The project is made up of three linear systems of housing integrated with services, public space, rest areas, meeting places for local residents, and especially green space. The components of the housing unit are reduced numerically in order to standardize them. They can be combined to obtain a large number of spatial solutions and dimensions and thus satisfy the housing needs of different users. The variety of possible combinations overcomes any concern regarding monotony and at the same time allows control of volumetric and expressive quality. Finally, the project addresses environmental sustainability and overall efficiency through the use of natural ventilation and lighting compatible with the site’s climatic characteristics; the use of building technologies and innovative mechanical systems having low environmental impacts; the integration of components that produce energy from renewable energy sources (Fig.4).

Conclusions

These design experiments are part of the HousingLab research whose goal is to overcome the enduring resistance - in Italy - to the use of the modular home built with industrially-produced components and elements. The projects are based on an approach that, as early as the concept phase and into further design development, is based on components: a limited number of two and three dimensional modules that can be assembled to obtain different configurations of domestic space. Aside from the economic and environmental sustainability of the building projects, one of the main goals of the research project is flexibility (Battistacci 2006: 113-138) relating not only to use but to user customization.

These goals are achieved through two approaches. The first (in the "Cohousing at Fidenza" and "solidarity Fano" projects) provides for a system of "spatial modules" that are constant in size and internal organization and that can be combined within a network of plan modules. This makes for an extremely variable number of dwelling types using a very small number of building components, usually industrially-produced. Variety and customization of the different types derive from the multiple combinatorial possibilities.

The second approach stems from the idea of a prefabricated and easily-transportable "three-dimensional modular unit" equipped with structural and mechanical elements that can be readily assembled, even by users. The units can be chosen from a catalogue and customized based on the number of components in relation to the size and type of house, to the reversibility of the spatial modules, to the wide range of materials and solutions for interior partitions, exterior cladding, windows, and roofing. This system is distinguished by the possibility of being able to use the same spatial modules for free-standing and groups of dwellings as well as for integrating with existing residential context for example by adding elements to facades or roofs. Like the "Zusatzraum" system, the small multifunctional space designed by Exilhäuser architekten in 2001, those developed in the "Ecohousing kit - Caterpillar" and "Living box" projects respond to the needs of the contemporary city, offering easy-to-implement, cost-effective and high-quality design solutions.
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Abstract
Mass customisation involves the provision of product variants that fulfil clients’ specific requirements seeking to increase product values. The configuration process involves a chain of decisions, which needs to be undertaken to create product variants that meet each client specific requirements. In this paper, this chain of decisions is conceptualized in terms of customisation units. Each customisation unit encompasses a customisable attribute (e.g. size, colour) and the range of items offered for this attribute. A design science approach was adopted in this investigation. In this approach, knowledge is produced by creating and testing a solution, which provides practical and theoretical contributions. A method is proposed to analyse and improve the configuration process by conceptualizing this process as a tree diagram. The proposed method is used to analyse the configuration process developed by organisations of the house-building sector based in the U.K. and Brazil: a manufacturer of floor tiles, contractors, and registered providers. These analyses enabled a comparison of the distinct configuration processes adopted. In addition, problems associated to the configuration process (such as burden of choice) and opportunities for improvements were also identified. Finally, alternative chains of decision were also devised based on these analyses to address the problems identified.

Keywords: Mass Customisation, Housing, Co-Design, and Configuration Process.

Introduction
Mass customisation involves the fulfilment of clients’ specific requirements through the provision of customised products (or product variants) that should fall within the scope of customisation offered by an organisation. The scope of customisation is defined by a set of customisable attributes (e.g. colour, size, shape) and the range of items offered for each one of them (e.g. small, medium, and large are items for the size attribute). In general, a product variant is configured once an item for each customisable attribute is selected. For example, if the customisable attributes are colour and size, a product variant is defined once a particular size and colour are selected. Since most customisation strategies involve more than one customisable attribute, the configuration process involves a chain of decisions rather than a single decision. This chain of decisions can assume different forms depending on technical constraints. For instance, an attribute might need to be defined prior to another. However, it can also be shaped to some extent by the organisation offering the customisation strategy.

It is necessary to shape this chain of decisions so that product variants can be created without much effort, avoiding some of the problems identified by Piller et al. (2005), such as the burden of choice and matching needs with specifications. In addition, configuring a product variant is often a creative problem solving process that may add value and increases client satisfaction (Kumar 2004). Therefore, the chain of decisions should be devised so that it is enjoyable and generates those benefits. Although the importance of the configuration processes is pointed out in the literature, most studies do not focus on translating this knowledge into tools that can be used by organisations to devise or improve such processes.

This paper aims to fulfil this research gap by proposing a method to analyse and improve the chain of decisions of a configuration process. In order to illustrate that, this method was used to analyse the configuration processes of four organisations from the house-building sector and also to identify improvement opportunities. This paper builds upon the results of an investigation (Rocha 2011), which proposed a conceptual framework for defining customisation strategies in the house-building sector. The analysis of the configuration process presented in this paper corresponds to one of the decision categories of that framework, named configuration sequence.
Configuring a product variant

The chain of decisions used for configuring a product variant may be carried out either by the organisation or by the clients. In the former situation, the configuration process involves a transparent approach (Gilmore and Pine 1997), since the definition of product variants is based on clients’ requirements but these are not aware that a customisation is taking place. In the latter situation, it involves a collaborative approach (Gilmore and Pine 1997) since clients and the organisation engage in a dialogue to create the product variant. This approach is similar to what is termed by Piller (2004) as product co-design, in which the clients take active participation in creating the product variant. A major advantage of co-design (or a collaborative approach) in configuring a product variant is the sense of ownership instilled in the clients, besides the recognition that the product was tailored according to their requirements (Piller and Kumar 2006). Schreier (2006) points out other benefits of clients’ participation in creating product variants:

(i) The perceived uniqueness of the self-designed product: this is closely related to the style dimension, proposed by Piller et al. (2005), i.e. a customised product becomes a means to communicate the client’s identity;

(ii) The process benefits: the joy that results from the design act itself and that has a positive impact on the value of the outcome of the design process, namely, the self-designed product; and

(iii) The ‘pride of authorship’ effect: it is concerned with pride in having done it oneself. It emanates from the cycles of trial and error and learning by doing that the client is likely to undertake.

Although there are benefits in clients’ active engagement in configuring a product variant, there are also problems associated to it. For instance, it is not a simple task to elicit and capture clients’ requirements and clients may have difficulties in clearly expressing what they want or need (Zipkin 2001). Moreover, the client often defines the product in terms of its attributes, which might not contribute towards the definition of abstract goals and objectives in terms of value for the client. Clients may also specify attributes that they considered valuable, but that in fact might not be aligned with the desired outcomes. Piller (2004) and Piller et al. (2005) outline other problems that can happen when clients engage in the configuration process:

(i) Burden of choice: it happens when an excessive-

ly large number of options is offered, overwhelming clients and increasing the complexity in configuring a product variant. Hence, increasing the options available for a product does not necessarily yield superior levels of satisfaction; and

(ii) Matching need with product specification: clients might also have difficulties in configuring a product variant due to the lack of knowledge and skills to transfer their requirements into an explicit product specification. Even a common product like a pair of sport shoes can have a complex configuration process if the client has to explicitly decide between different widths, sizes, and colours.

In summary, there are pros and cons in collaborative and transparent approaches. Configuration problems are avoided when a transparent approach is adopted. However, the benefits that emanate from client active engagement are also lost. Therefore, the definition of the approach to be adopted (transparent, collaborative, or a mix of both) is a strategic decision that should be made by the organisation developing the customisation strategy. In any case, the chain of decisions of a configuration process should enable a product variant to be created without too much effort, regardless of who (clients or organisation) will be involved in this process. Clearly, should the configuration process involve a collaborative approach, minimization of configuration problems and exploitation of benefits that arise from clients’ engagement should also be included as goals.

Research method

This investigation adopts a design science approach, which is concerned with the devising and evaluation of man-made artefacts aiming to resolve real-world problems (March and Smith 1995). In this approach, knowledge is produced by creating and testing a solution that manipulates a particular phenomenon (Vaishnavi and Kuechler 2007). It differs from formal sciences such as mathematics, which produce knowledge by creating abstract propositions and testing their internal consistency (Van Aken 2004). It also differs from explanatory science, which produce knowledge by proposing scientific claims (i.e. descriptions, explanations, causality) concerning a phenomenon and empirically testing them (March and Smith 1995). Two fundamental activities of design science research are: (i) develop and apply solution, and (ii) test its usefulness in solving real world problems. Hence, the method proposed here is defined as a solution whose usefulness and practical contribu-
Defining the chain of decision of a configuration process

In the proposed method, the chain of decisions is modelled as a tree diagram, which has been explored in customisation studies (e.g. Cao et al. 2006, Du et al. 2003). The first step to define this chain of decisions (or tree) is to elicit the customisation units used in the customisation strategy. Each customisable attribute and the range of items offered for it forms a customisation unit. Figure 2 presents a hypothetical example in which there are three customisation units: C1, C2, and C3. The tree represents the chain of decisions to define a product variant. In the example of Figure 1, there are four customisation units. Firstly, a decision concerning C1 needs to be made (i.e. a floor plan needs to be selected). Then a decision concerning C2 and C3, namely the floor finishing for the office and the colour for the wall need to be selected should be made, if the layout previously selected in C1 has an office. If not, only a decision concerning C2 should be made.

The second step is to analyse the tree attributes, namely, the number of horizontal and vertical levels. The horizontal and vertical levels express the interdependency among these decisions (Figure 1). Horizontal levels mark the number of branches that one needs to go through until all the necessary decisions to define a product variant are made. Vertical levels mark the number of customisation units that needs to be simultaneously considered in each branch. If a branch contains two customisation units, such as branch 2.2 in Figure 1, it means that the decisions concerning these customisation units do not need to follow a particular order.

As illustrated in Figure 1, each branch has a particular number of vertical levels: branch 2.2 has two vertical levels, whereas branches 1 and 2.1 have only one vertical level.

By varying the amount of vertical and horizontal levels, four hypothetical types of trees are proposed Figure 2. They are defined as hypothetical because they might not exist in the real world, but illustrate the implications that distinct decisions concerning the number of levels can have. Also most configuration processes in the real world cannot be strictly categorised as one type of tree or another, but as a combination of those types.

Type 1 involves only one customisation unit, implying that there is only one vertical level and one horizontal level (Figure 2). This is the simplest configuration process. Type 2 has several horizontal levels but only one customisation unit to be considered at each level (Figure 2). The advantage of this type of configuration process is that the decision process is simple because it involves the selection of an item of only one customisation unit at the time. Its drawback is the fact that clients might not have an overview of the scope of the customisation at the outset once it is gradually communicated as they go through the configuration process. Type 2 is appropriate when there is an interdependency or hierarchy among the customisation units. In those
cases, presenting sequentially the customisation units tends to facilitate the configuration process. Type 3 has a single horizontal level and several vertical levels (Figure 2). In this type of configuration process, the client has to consider several customisation units at the same time. The advantage is that the client can have an overview of the scope of the customisation offered and also go back and forth in defining the customisation units until reaching the desired product variant. Nonetheless, this process can be time consuming and perceived as difficult by the client. Finally, type 4 would be a combination of the types 2 and 3 in which there are several levels, each one with several customisation units to be considered. It might be challenging to configure a product variant in this tree since there are several horizontal levels to be considered with several customisation units in each of those levels.

Results of the application of the proposed method

Case study 1

In case study 1, there are five customisation units: C5 – shapes, C4 – colours, C3 – package size (different package size will be offered to different market segments), C2 – promotion modes (tiles will be advertised differently depending on the market segments), and C1 – off-the-shelf mixes (each mix will have a particular shape of tile and colour). Company 1 plans to offer the floor tiles to two different market segments: contractors and homeowners performing renovations or constructing their own homes. Different packages sizes and promotion modes will be used for each segment.

The configuration process involves only one tree that has one branch in the first level and two branches in the second level (Figure 3). The decision in the first horizontal level involves C3 – package sizes and C2 – promotion modes. The
decision in the first level is carried out by Company 1 which decides how the items in these two customisation units should be combined before proceeding to the second level: (i) large package size and promotion mode 1 will be used for contractors; and (ii) small package size and promotion mode 2 will be used for homeowners. Branch 2.1, entailing C4 – colour and C5 – shapes, will be offered to contractors, and branch 2.2, involving C1 – off-the-shelf mixes, will be offered to individual clients. The fact that Company 1 undertakes part of the configuration process facilitates such process from the clients’ perspective. Clients only need to make a decision concerning one or two customisation units at the second horizontal level (Figure 3). This is similar to type 1 of the hypothetical trees, which is the simplest configuration process.

**Case study 2**

In case study 2, there are five customisation units: C1 – floor plans per block (for each block of the building, a different floor plan is used), C2 – colours for plugs and switches, C3 – floor tiles, C4 – floor plans (for each apartment, different floor plans are offered), and C5 – free customisation of layout and specification (client can commission interior designers to develop a bespoke design for the apartment). Different sets of customisation units and trees are used depending on the area of the apartments (Figure 4). Tree 1 provides the largest degree of customisation since it entails C5. It is most often offered in projects that have apartments with an area of 201 m² or more. Tree 3 is offered in projects that have apartments whose area range between 101 and 200 m². Trees 3 and 4 are used in projects that have apartments with an area of 100 m² or less.

Trees 2, 3, and 4 have a simple chain of decision given that they only have one horizontal level with one or two customisation units to be considered. Conversely, tree 1 has two horizontal levels and one of these entails three customisation units,
which requires additional effort from the client since they have to simultaneously select three items (Figure 4). Tree 1 has two horizontal levels because the client first selects the apartment plan (C1), when the apartment is purchased, and later receives a letter from Company 2 explaining the other customisation units (C2, C3, and C5) as depicted in Figure 4. The decision concerning C2, C3, and C5 are located in the same horizontal level because these are presented to the client at the same time, when a letter is delivered. A major difficulty of this tree is that the items in C2 and C3 change, depending whether the client uses C5 or not. If a client decides to commission a designer to develop a bespoke design for the apartment, he/she can also have bespoke tiles and plugs and switches in C2 and C3. If not, they have to select tiles and plugs and switches from the set of items offered by Company 2.

Figure 5 proposes an alternative configuration process for tree 1 that aims to address these problems. C5 is broken down in two customisation units: C5.1 and C5.2. In the former, clients have to decide if they would like to have the free customisation of layout and specifications or not. If so, they will go to branch 3.1 were they should provide the bespoke design of the apartment, which may have the bespoke floor tiles (C3) and switches (C2). If not, they will go to branch 3.2 and will have to select the floor tiles (C3) and switches (C2) from the set of items offered by Company 2. This alternative chain of decisions is likely to simplify the configuration process since the items available in C2 and C3, which depend on the decision concerning C5.1, are more clearly expressed.

**Case study 3**

In case study 3, there are six customisation units: C6 – dwelling types, C5 – bathroom fit-outs, C4 – kitchen fit-outs, C3 – external doors and windows, C2 – roofing, and C1 – external cladding. They are organized in one tree with only one branch because the decisions concerning all customisation units are simultaneously made (Figure 6). It must be emphasised that the tree presented in Figure 6 is tentative due to the fact that the configuration process was not clearly established when this investigation was undertaken. This tree has seven vertical levels and only one horizontal level. This implies that the client has to consider simultaneously several customisation units, which may create burden of choice, since there are several customisation units that need to be considered at the same time and the client might go back and forth in selecting the items for each of these. Yet, having all customisation units in a single branch provides the client with an overview of all the customisable items of a product.
The configuration process in this case study seems to work if the client selects the same item in each of the customisation units for all the dwelling units of a scheme. For instance, if the client selects thirty dwelling units and all of these have the same specification in terms of the roofing, windows and doors, external cladding, and kitchen and bathroom fit-outs. Yet, the configuration process does not enable clients to configure sub-sets of dwellings with different specifications. This might be necessary, for example, if a client wishes to create different streetscapes for a scheme. The main problem is that C6 - types of dwelling is mixed up with the other customisation units in a single branch, when in fact it should be defined prior to them.

Figure 7 illustrates how the configuration process could be changed to address these problems. In the first level, the client would select the types of dwellings. In the second level the client would create sub-sets of dwelling units that would have the same features in terms of finishing, fixtures, roofing, and windows and doors. In other words, the items selected in C1, C2, C3, C4, and C5 would apply to all dwelling units forming each subset. Ultimately, if clients would like each dwelling unit to be different from the others in terms of specifications, they could define each of these as a subset.

**Case study 4**

In case study 4, product variants are residential schemes, which are created by mixing and matching dwellings from a defined set of dwelling designs. These dwelling designs are organized in two customisation units (Figure 8): C1 – eight dwelling designs to be used in a particular location in the UK that has specific requirements for social housing, and C2 – nine dwelling designs to be used elsewhere.

There is only one tree with one branch in the first level and two branches in the second level (Figure 8). The branch in the first horizontal level is related to the location of the plot, which is not under the control of the consortium members, but that defines which branch at the second level will be used. Depending on the location of the plot, one customisation unit or the other will be used. Case study 1 has a similar tree in terms of the number of levels. Case studies 1 and 4 show how chains of decisions, similar in terms of levels, can be actually different depending on who makes the decisions at each level. As previously discussed, in case study 1 it is Company 1 that makes the decision at the first level. In that study, the clients make the decision at the second level (branches 2.1 and 2.2). Hence, from the clients’ perspective, it is a simple configuration process because it entails a single horizontal level, involving only one or two customisation units. Alternatively, in case study 4, the decision in the first level is not made by the registered providers but hinges on the scheme location. Thus, only the decision at the second level concerning the mix and amount of dwellings to be used in the scheme is made by the registered provider.

**Discussion**

All customisation strategies have a configuration process that involves a chain of decisions to define product variants that meet clients’ specific requirements. In this paper, this chain of decisions is conceptualized in terms of the customisation units used in a customisation strategy and the sequence that needs to be followed in selecting the item in each of them. Modelling this process as a tree helps to elicit this chain of decisions and also the form of client engagement (transparent or collaborative)
used for each customisation unit. This also enables problems associated to the configuration process (e.g. burden of choice, matching need with specifications) discussed in the literature (e.g. Piller 2004; Piller et al. 2005; Piller and Kumar 2006) to be minimized or avoided. In addition, it also allows companies to improve this process to enhance benefits such as perceived uniqueness, ‘pride of authorship’ effect, among others (Schreier, 2006).

Conclusions

This paper proposes a method to analyse and improve the chain of decisions that need to be made to configure a product variant. In order to illustrate the applicability of this method, it was used to analyse the configuration process developed by four organisations of the house-building sector. Based on these analyses, alternative chains of decision were proposed in studies 2 and 3 seeking to address problems identified. The results of this paper suggest that the method is useful from a practical viewpoint and can be employed by organisations of the house-building sector to analyse and improve configuration processes. Future studies should focus on applying the proposed method to devise new configuration processes, rather than analyse and improve existing ones.

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Introduction

As scientists elucidate the mechanism of global warming in increasing detail and how carbon compounds produced from economic activities affect climate change, global warming has become recognized not only as an economic issue, but also as a comprehensive global issue vital to ecological protection. Accordingly, the realization of a low-carbon society has become one of today’s greatest international priorities. Some remain sceptical, however, about the true economic value of green buildings. A thorough analysis has yet to be conducted to evaluate whether green buildings realize income increases commensurate with the enormous initial investments required, although it is clear that cost savings do result from lower energy consumption. This paper shows through a series of analyses that certain market conditions must be in place in order for green buildings to produce economic value. Specifically, it used the hedonic approach to clarify whether or not there is added economic value, focusing on the new condominium market in the Tokyo metropolitan area. Based on a demonstration analysis of the housing market, the author shows that new condominiums with “green labels” using “sustainable measures” command a premium of approximately 5.8% in asking prices and 4.7% in transaction prices.

Keywords: Green building, Sustainable Measures, present value, CASBEE, Hedonic Approach.
factory that discharged air pollutants and impaired the health of community residents; for the issue under review, the “air pollutants” are carbon compounds and the “community residents,” or the health victims, are the earth, but the overall structure is the same. Taken this way, it would be easy to imagine there is a need for social responses to buildings that discharge carbon compounds. Given the above points, how much value, if any, does the market place on green buildings? And if the market does place value on green buildings, through what mechanism are they differentiated?

This paper is intended to provide a review of the economic value of green buildings and analyse how much value the concept of environmental friendliness actually adds to buildings.

How Green Buildings Produce Economic Value

How Real Estate Prices are Determined

Let’s start with a normative analysis for the economic value of green buildings. While outlining the determining mechanism of property value, the kind of mechanism that enables green buildings to have a premium shall be outlined. The determining mechanism of property value may be formulated using a durable goods economic value model framework.

\[
P_t = \frac{P_0}{1 + r \left(1 + \gamma \left(1 + r \right) \right)^{-t}} + \frac{P_{t+1}}{1 + r \left(1 + \gamma \left(1 + r \right) \right)^{-t}} + \cdots + \frac{P_{T}}{1 + r \left(1 + \gamma \left(1 + r \right) \right)^{-t}}
\]

In addition, the discount rate \( r \) for the property is determined as the result of comparison with investments in stocks, bonds, etc. (asset choice), and may be strictly defined as \( R_k + R_{l} - \gamma \). Taking the return on safe investments \( R_k \) on government bonds, which are a benchmark for financial investments, and the like as a base, this is determined based on the risk premium for the relevant property \( R_l \) and the income appreciation rate for the relevant property \( \gamma \) (Gordon, 1959). Moreover, this risk premium \( R_l \) may be expressed as in Formula (2).

\[
R = f(L(x), \xi)
\]

Here, \( L(x) \) indicates the liquidity risk, and the unforeseen risk \( \xi \) that could not be forecast at the time of investment is also included.

Income Variation Effect

As outlined in the previous section, it has been reported that a premium exists with respect to income for green buildings. Assuming that these findings are correct, the question of why income increases for green buildings is important because the sustainability and extent of future premiums will change significantly based on the underlying factors. Eichholtz et al. (2009b) analysed what kinds of companies are located in environmentally friendly buildings. Their results showed that companies with a strong preference for being located in environmentally friendly buildings can be categorized into six types: a) tertiary industry companies, for which energy cost savings has a major effect on ensuring profits, b) companies at which there is strong demand for Corporate Social Responsibility (CSR) from shareholders, c) companies which are sensitive to their environmental load (companies such as those in the oil and energy industries that deal in commodities which are a factor in environmental loads), d) companies with many highly educated personnel who generate high added value, e) government or public institutions, and f) companies sensitive to consumer behaviour (companies such as food manufacturers whose profits are directly linked to their reputation with consumers).

In the case of a), the tenant company forecasts a relatively significant expense reduction effect, and even if the nominal paying rent is high it will be offset by this effect. Based on this, it may be anticipated that the company judges that a practical rent reduction effect can be expected. This falls under the expense reduction effect discussed in the next section.

Expense Reduction Effect (\( \xi \))

In comparison to other buildings, green buildings are designed so that they have greater energy efficiency. Specifically, energy costs will decrease by increasing insulation and the like. This kind of effect is greater in cold regions (i.e., it changes based on climate). Furthermore, technologies have been introduced that reduce the various kinds of energy generated by activities in buildings, by means of facilities that increase energy efficiency such as lighting. There is also a movement toward attempting to control carbon emission amounts by using alternative energy such as solar power and geothermal power. The economic value accompanying these kinds of increases in energy efficiency is linked to the increased value of green buildings through the reduction of \( \xi \) (\( \xi^{(1)} \cdots \xi^{(n)} \)).

This effect is the added economic value indicated by Dian and Miranowski (1989) and Barfi et al. (2005).
Discount Rate/Liquidity Risk Change Effect

The discount rate is one of the most important factors in determining property values. With regard to the issue of determining the discount rate for green buildings, research focusing on socially responsible investment funds is a useful reference. Socially responsible investment funds are composed of investment funds focusing only on companies with externalities that have satisfied certain standards relating to social contributions. Studies have been published indicating it is possible to obtain relatively high returns from investment in such funds compared to regular investment funds. However, with regard to outcomes, different results have appeared based on differences in the analysis period, etc. (e.g., Renneboog and Zhang, 2008; Galema et al., 2008).

Even if profitability is not high, should liquidity increase, it is to be expected that the discount rate will decrease via the risk amount decreasing. This being the case, the economic value would increase through this decrease in the risk amount.

Green Building and Housing Price

Hedonic Model and Data

The extent of the economic value possessed by green buildings based on the results of empirical analysis focusing on the new condominium market in the Tokyo metropolitan area will now be presented (Shimizu, 2010, 2012). The value of a house changes according to factors such as the number of rooms, balcony size, toilet facilities, kitchen and bathroom facilities, earthquake resistance, and other attributes. In particular, residential houses are priced in a differentiated market according to performance and functionality because each is unique (in other words, no other goods are totally equivalent in terms of location, etc.). The most effective method for analysing such a market is the hedonic approach, which considers market value as a group of various performance and functional values (a group of attributes) and estimates the product price using statistical regression analysis. The price is expressed by an equation consisting of the attribute groups, which is known as the “hedonic price function.” Using this function, we can estimate the amount of value that consumers attach to each type of function and performance.

This study is intended to compute the economic value of the green features of environmentally friendly buildings, using the hedonic approach. Specifically, the pricing mechanism for new condominiums is defined as follows:

In general, the condominium unit price is affected by differences in the unit’s performance, including its “proprietary area” and “number of rooms,” as well as by accessibility, including “proximity to the nearest railway station,” and the apartment building’s performance, including its structure (). The environmental performance of the building is included in this group of attributes. The price is also influenced by the characteristics of the surrounding environment, such as the local atmosphere and commercial zones (). This is known as the “neighbourhood effect.” If an analysis is performed across a wide area covering more than one administrative ward, attention must also be paid to differences across a wider area, such as “proximity to the central business district (CBD)” and differences in administrative services available at the regional level. Therefore, attention is also paid to differences in environmental features across a wider area than the neighbourhood ().

Demonstration Analysis-Estimation Model

For hedonic function calculation purposes, we estimate two demonstration models, Models 1 and 2. As explained above, the data includes asking and transaction samples. This study stacks them and estimates the difference between asking and transaction samples using a transaction dummy (TrDi). In other words, we apply the hedonic price formula to the 82,270 samples (the sum of asking and transaction samples).

The effect of green labels (), which is the subject of this research, is estimated using several different types of dummy variables for green labels. First, we estimate the average effect of green labels independently of the environmental performance level and the time of transaction, then estimate how the effect of green labels changes with the time of transaction using the cross term of the environmental performance level and the time of transaction. Even if sellers ask for higher prices because of green labels or environmental performance offered, buyers or consumers may not accept the price differences and the final transaction prices may be almost the same as those for condominiums without green labels. By adding a cross term of green label () and transaction dummy (TrDi), we can estimate both of them.

First, in Model 1 we analyse price gaps between condominiums with and without green...
labels under the Tokyo program, using a dummy for the environmental variable (1) that shows whether or not these labels are obtained. The possibility of the effect of green labels being different between asking and transaction samples is represented by a cross term. The function form is a semi-logarithm, and square terms are added for some variables, such as the size of the building. This is intended to deliberately exclude the possibility of an alternative variable for building size being created because green labels are required for buildings whose total floor area exceeds 10,000 square meters. For explicated variables, the natural logarithm of the price per square meter of condominium unit is used. The results, therefore, provide a rough estimate of the percentage by which the price changes along with each variable.

In order to assess the impact of green labels on housing price, the following two estimation models are used:

\[
\text{Model 1:} \quad \log \left( \frac{P_{C_t}}{F_0} \right) = a_0 + a_1 C_0 + \sum a_k X_k + \sum a_t T_{t} + a_0 C_0 T_0 + a_0 C_0 T_1 + a_0 C_0 T_2 + \epsilon_{t,2}
\]

Where

- \( P_{C_t} \): Price of condominium unit \( t \) in apartment building at time \( t \)
- \( F_0 \): Floor area of condominium unit \( (\text{square meters}) \)
- \( C_0 \): Green label for apartment building
- \( X_k \): Architectural and locational characteristics of condominium unit \( t \) in apartment building \( k \) (\( k \)-th characteristics)
- \( T_{t} \): Time dummy \( t \) (0 years 2005 to 2006)
- \( T_{0} \): Transaction dummy \( t \) for asking price

In Model 2, a cross term of \( C_0 \) and \( T_{0} \) is added to determine how the effect of green labels changes over time.

\[
\text{Model 2:} \quad \log \left( \frac{P_{C_t}}{F_0} \right) = a_0 + \sum a_k X_k T_{t} + \sum a_t T_{t} + \sum a_0 C_0 T_{0} + \epsilon_{t,1}
\]

**Estimation Results**

The estimation results are shown in Table 1. For both models, the determination coefficient adjusted for degrees of freedom was as favourable as 0.779 and 0.784. Also, the estimation results were consistent with expected results for each estimated variable. First, Model 1 showed that asking prices were around 5.8% higher for condominiums with green labels. The effect of green labels was determined after controlling for the effects of all factors, such as the building’s size, quality, location and ambient environment, the condominium unit’s characteristics, the time of transaction, the developer, and the constructor. Developers must have made additional investments to enhance the buildings’ environmental performance; the reason was shown to be that they anticipated higher selling prices. How much transaction prices were different from asking prices was estimated using a dummy variable that identifies transaction samples and a cross term for transaction price and environmental performance dummies. In other words, we estimated both the general difference in transaction price level and the difference in transaction price due to the difference in green rating. The constant dummy for the transaction price was estimated at -0.011, which is statistically significant at 1%. This shows that actual transactions were concluded at prices around 1.1% lower than the asking prices. The cross term for transaction price and environmental performance dummies was estimated at 0.0011. These estimation results are interpreted as follows. For condominium units with green labels, a 5.8% premium was included in the asking price, the final transaction price was 4.7% (5.8% minus 1.1%) higher than that for condominium units without green labels. In other words, the effect of green labels was observed in the transaction price too.

Then, Model 2 was analysed to measure the time effect. In 2005, the time effect was a negligible 0.88% for the transaction price because the program just started in October of the same year. This figure should be interpreted as showing zero effect, rather than a negative effect. In 2006 and 2007, however, transaction prices included premiums of 3.7% and 5.5%, respectively, and in 2008 a slightly lower premium of 4.8% was included. In 2009 and 2010 transaction prices included premiums of 7.5% and 4.5% with green labels or sustainable measures.

**Sustainable Measures and Economic Value**

How will green buildings ultimately be valued by the real estate market? What conditions should be in place for green buildings to produce economic value? There must be certain market conditions in place for green buildings to produce economic value. In the case of real estate investment (including residential property investment by household), any systemic change will have a strong impact on investment performance, so it is very important to know what types of change will have a specific impact on the market. Behind this lies the assumption that the level of economic value now awarded by the market is lower than socially expected. The following is a normative analysis of this effect based on empirical results in previous section.

In order for the inherent economic value of
Table 1: Estimation Result of Hedonic Equations.

<table>
<thead>
<tr>
<th></th>
<th>Model (1)</th>
<th>Cross Term</th>
<th>Model (2)</th>
<th>Cross Term</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>× tvD</td>
<td></td>
<td>× tvD</td>
<td></td>
</tr>
<tr>
<td><strong>G</strong>: Green Label Effect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G: Green label dummy</td>
<td>0.0384</td>
<td>-0.0111</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>G × 2005 year dummy</td>
<td>-</td>
<td>-0.0578</td>
<td>-</td>
<td>-0.0490</td>
</tr>
<tr>
<td>G × 2006 year dummy</td>
<td>-</td>
<td>0.0414</td>
<td>-</td>
<td>-0.0034</td>
</tr>
<tr>
<td>G × 2007 year dummy</td>
<td>-</td>
<td>0.0448</td>
<td>-</td>
<td>0.0108</td>
</tr>
<tr>
<td>G × 2008 year dummy</td>
<td>-</td>
<td>0.0848</td>
<td>-</td>
<td>-0.0338</td>
</tr>
<tr>
<td>G × 2009 year dummy</td>
<td>-</td>
<td>0.1048</td>
<td>-</td>
<td>-0.0294</td>
</tr>
<tr>
<td>G × 2010 year dummy</td>
<td>-</td>
<td>0.0372</td>
<td>-</td>
<td>0.0073</td>
</tr>
<tr>
<td><strong>X</strong>: Building Characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S: Floor space</td>
<td>0.015</td>
<td>***</td>
<td>0.014</td>
<td>***</td>
</tr>
<tr>
<td>TS: Distance to the nearest station</td>
<td>-0.010</td>
<td>***</td>
<td>-0.009</td>
<td>***</td>
</tr>
<tr>
<td>Bus: Bus area dummy</td>
<td>-0.202</td>
<td>***</td>
<td>-0.195</td>
<td>***</td>
</tr>
<tr>
<td>TS × Bus</td>
<td>0.010</td>
<td>***</td>
<td>0.010</td>
<td>***</td>
</tr>
<tr>
<td>Total building area</td>
<td>3.14E-08</td>
<td>*</td>
<td>3.60E-08</td>
<td>*</td>
</tr>
<tr>
<td>Housing Design Performance Evaluation Document dummy</td>
<td>0.007</td>
<td>***</td>
<td>0.007</td>
<td>***</td>
</tr>
<tr>
<td>Housing Construction Performance Evaluation Document dummy</td>
<td>0.006</td>
<td>***</td>
<td>0.006</td>
<td>***</td>
</tr>
<tr>
<td>Management cost</td>
<td>0.007</td>
<td>***</td>
<td>0.007</td>
<td>***</td>
</tr>
<tr>
<td>Building managed dummy 1: Visiting type</td>
<td>-0.003</td>
<td>***</td>
<td>-0.005</td>
<td>***</td>
</tr>
<tr>
<td>Building managed dummy 2: 24-hour’s type</td>
<td>0.022</td>
<td>***</td>
<td>0.018</td>
<td>***</td>
</tr>
<tr>
<td>General leasehold dummy</td>
<td>-0.011</td>
<td>***</td>
<td>-0.008</td>
<td>***</td>
</tr>
<tr>
<td>Fixed-term leasehold dummy</td>
<td>-0.038</td>
<td>***</td>
<td>-0.037</td>
<td>***</td>
</tr>
<tr>
<td>Corner dummy</td>
<td>0.022</td>
<td>***</td>
<td>0.020</td>
<td>***</td>
</tr>
<tr>
<td>SRC dummy</td>
<td>0.025</td>
<td>***</td>
<td>0.020</td>
<td>***</td>
</tr>
<tr>
<td><strong>MK</strong>: Market Characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transaction completed rate in first month</td>
<td>0.004</td>
<td>***</td>
<td>0.003</td>
<td>***</td>
</tr>
<tr>
<td><strong>NE</strong>: Neighboring Environment Variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT: Travel Time to central business district</td>
<td>-0.002</td>
<td>***</td>
<td>-0.002</td>
<td>***</td>
</tr>
<tr>
<td>F.A.R.: Floor Area Ratio</td>
<td>-0.001</td>
<td>**</td>
<td>-0.001</td>
<td>**</td>
</tr>
<tr>
<td>City planning use dummy: Commercial</td>
<td>-0.007</td>
<td>***</td>
<td>-0.006</td>
<td>***</td>
</tr>
<tr>
<td>City planning use dummy: Industrial</td>
<td>-0.040</td>
<td>***</td>
<td>-0.039</td>
<td>***</td>
</tr>
<tr>
<td>500m Mesh: Average building rank in mesh</td>
<td>0.029</td>
<td>***</td>
<td>0.027</td>
<td>***</td>
</tr>
<tr>
<td>500m Mesh: Standard deviation of building rank in mesh</td>
<td>-0.018</td>
<td>***</td>
<td>-0.017</td>
<td>***</td>
</tr>
<tr>
<td>500m Mesh: upper 65 age population</td>
<td>-0.016</td>
<td>***</td>
<td>-0.015</td>
<td>***</td>
</tr>
<tr>
<td>500m Mesh: Rental housing household</td>
<td>-0.050</td>
<td>***</td>
<td>-0.048</td>
<td>***</td>
</tr>
<tr>
<td>500m Mesh: Professional and technical workers</td>
<td>0.291</td>
<td>***</td>
<td>0.284</td>
<td>***</td>
</tr>
<tr>
<td><strong>D</strong>: Time dummy**</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Other dummy</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Railway dummy**</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Location (ward) dummy***</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Developer dummy****</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Construction company dummy*****</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Number of observations = 47,816
Adjusted R-square = 0.779

Significant at 10%:*, Significant at 5%:**, Significant at 1%:***
*2001 to 2011 **66 railway dummies ***22 local (ward) dummies
****10 Developer's dummies *****14 construction company dummies
green buildings to be realized in the market, it is necessary, first of all, that information about the green features of real estate be accumulated, disclosed, and distributed. In addition, market participants who have acquired such information need to change their behaviour. If an investment is defined as an act that produces a certain economic value, it is possible to say that we invest in real estate not as a “physical matter,” but as a “mass of information.” Both individual households that invest in houses and enterprises that invest in large office buildings see the “physical matter,” but its value cannot be measured accurately based on a “physical” review. Not until information relating to the “physical matter” is scrutinized can its value be determined precisely. In other words, we invest in real estate as a “mass of information.”

Real estate information can be roughly divided into (a) information about the building’s economic performance, such as income and expenses, and (b) information about its architectural performance. Architectural performance information consists of information about public regulations (concerning construction techniques, earthquake resistance, etc.) and environmental regulations (concerning soil contamination, the use of asbestos, etc.). For investment assets, such information is often obtained from engineering reports, while for residential houses, it is available from documents describing important matters or housing performance assessment reports, the latter of which are becoming increasingly common. Market participants implicitly change their behaviour on the basis of this information. The first thing that is necessary to transform their behaviour is to include specific information about green buildings in this mass of information and to disseminate this information widely.

Recent years have seen the increasingly widespread use of an information disclosure system that describes the environmental burden imposed by each piece of real estate. The Japanese system is called CASBEE, while overseas countries have certification systems such as BREEAM in the U.K. and LEED in the U.S. These environmental assessment standards are intended to measure the environmental burden that is potentially produced by a given piece of real estate. In Japan, certification is prescribed for development projects of certain sizes by the local government authorities. Not until this certification system (sustainable measures) and the disclosure of such information become widespread will market participants’ behaviour in the real estate market be transformed and the economic value of green buildings incorporated into the pricing mechanism. Information disclosure alone, however, will not change the behaviour of market participants. To influence their behaviour, the disclosed information needs to be both accurate and widely recognized.

Obviously, inaccurate information cannot be relied upon by market participants, but even accurate information will not transform their behaviour unless it is recognized as useful. “Recognizing information” means that information must be so clear and simple that it cannot fail to be recognized. There are trade-offs between these conditions. A more accurate assessment of environmental performance, for example, will require a wider range of yardsticks. For example, the U.K.’s BREEAM evaluates many environmental features, including (1) energy efficiency (carbon dioxide emission), (2) water use efficiency, (3) materials used in the building, (4) indoor environment (comfort and health for workers), (5) environment available on site, (6) accessibility, (7) management status, (8) contamination status, and (9) impact on the local ecology. The assessment results are therefore not so easy for general market participants to interpret.

Japan’s CASBEE is more precise and accurate than the other assessment systems (sustainable measures) because it evaluates buildings in terms of BEE (Building Environment Efficiency), that is their “environmental quality (Q)” and “environmental load (L).” The question remains, however, whether comprehensive indices, such as BEE, are viewed by market participants (including investors) as linked to market value or if they are easily “recognized.” In other words, these indicators only describe the physical condition of buildings and are not intended for conversion into a specific market value.

Conclusion: A Low-Carbon Society and the Real Estate Market

Does added economic value exist for green buildings? Focusing on the Tokyo new condominium market, this study answered this question in the same way as much previous research, by estimating a hedonic function. Here, with regard to the environmental value of green buildings, attention was focused on the extent to which a housing price differential occurs based on whether or not a condominium has a green label indicating that it is recognized as having a certain level of environmental performance under the Tokyo Green Labelling System for Condominiums.

The starting point in estimating a hedonic function was a standard model (Model 1) using the variables employed in most previous research. Next, the change in the effect accompanying the passage of time was also analysed (Model 2). The hedonic model that considered standard build-
ing/location/area characteristics (Model 1) showed that, in comparison to condominiums which did not have green labels, a premium value exists for green labels: the effect was 5.8% for the base asking price and 4.7% for the base transaction price (5.8% - 1.1%).

In addition, if one looks at temporal changes in the premium, while the effect on the base transaction price was limited to 0.9% in 2005, it rose to 3.8% in 2006, 4.5% in 2007, 4.9% in 2008, and 7.5% in 2009, and no value was found in 2010. Excluding the 2010 result, this shows that the effect of green labels became larger over time. A possible reason for this may be that the awareness of green buildings is increasing in the Tokyo condominium market and, what's more, the buyer segment that is actively seeking to invest in their value is expanding. However, more than a few problems remain. First, one could point out the problem of accuracy with regard to the green labels used as variables in order to distinguish the effect of green labels. The current labelling system is based on applications from developers, and it does no more than indicate buildings' anticipated environmental performance at the time of development. This means that the results will naturally change considerably depending on how green labels are defined. In addition, unless the added economic value of green buildings estimated here is absorbed to what extent compared to the amount of added development costs, it cannot be used for future policy development. It is possible that the premium of 4.6% may still be too low in comparison to the added development expenses.

Moreover, when it comes to the development of green building policy, the problem remains of how it will be infused into the existing housing market. Under the current system, green labels only cover newly developed buildings, but since it is expected that the existing housing market will expand in future, the application of labels to existing stocks will have to be considered. Notably, when it comes to a buyer’s choice of home, the decision is often made under strong budget restrictions. With the rapid changes in demographic structure, the population of people in their 30s and 40s – which is the home-buyer segment that generates the greatest demand for housing – is decreasing significantly. Since, given this context, it is to be expected that budget restrictions will become increasingly strict. It is likely necessary to keep monitoring whether there continues to be a fixed added value for green buildings. Additionally, the economic value of green buildings will change considerably depending on what kind of environmental regulations are implemented in future.

In order to develop green building policy, it is necessary to accurately estimate the extent of the economic value that may be anticipated. Along with these policy-related issues, the role that researchers must perform is also important.

REFERENCES


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Introduction

Generally in the UK, energy usage of households accounts for a significant portion of total energy consumption and carbon emissions. Scottish homes today are highly energy consumers emitting on average 3 tonnes of CO₂ per house annually and the amount exceeds the UK average of 2.75 tonnes of CO₂. Moreover, 26% of the households are actually facing fuel poverty and it is therefore a critical task to efficiently manage and minimise energy trends in housing in order to meet carbon dioxide (CO₂) emission reduction and energy consumption cut targets such as 80% overall cuts in carbon emissions by 2080 for the UK, compared with 1990 levels. The study has been undertaken within the Zero Energy Mass Custom Homes (ZEMCH) research network’s demonstration projects e.g. ‘ZEMCH 109’. The existing post-council end-terraced house was intended to be extended in South Ayrshire, Scotland in 2012. As part of the project, the Building Environments Analysis Unit (BEAU) research centre has conducted a post occupancy monitoring of the energy and indoor environmental conditions e.g. indoor air temperature, relative humidity and CO₂ levels in the Scottish affordable home which will also continue even after the construction of the newly built extension and the refurbishment of the existing home. It is therefore important for the successful demonstration of the ZEMCH 109 project and for the purpose of this study that a detailed monitoring and a post occupancy evaluation (POE) of the exiting NRGStyle home are performed sufficiently in order to investigate the relationship between energy consumption and the indoor environmental conditions and cross-checked with the accepted standards.

Abstract

Energy usage of households accounts for a significant portion of total energy consumption and carbon emissions. Scottish homes today are highly energy consumers emitting on average 3 tonnes of CO₂ per house annually and the amount exceeds the UK’s average of 2.75 tonnes of carbon dioxide. Moreover, 26% of the households are actually facing fuel poverty and it is therefore a critical task to efficiently manage and minimise energy trends in housing in order to meet carbon dioxide (CO₂) emission reduction and energy consumption cut targets such as 80% overall cuts in carbon emissions by 2080 for the UK, compared with 1990 levels.

Keywords: Scottish Home, Post Occupancy Evaluation, Housing Sector, Indoor Environments, Energy Consumption, Indoor Air Quality.
Approximately 20% of all dwellings in England suffer from mould growth and dampness to some degree (Oreszczyn and Pretlove 2000).

Several studies have analysed the impact of low ventilation rates and increased CO₂ concentrations on Indoor Air Quality (IAQ) complaints and health symptoms in buildings. It is found that high CO₂ concentrations in office buildings are associated with increased health symptoms from the occupants (Santamouris et al. 2008). The role of the relative humidity in the perception of indoor air quality and health continues to be an important question in the indoor environmental science community. Our understanding of its impact is relevant for developing indoor air quality guidelines and ventilation standards (Wolkoff and Kjaergaard 2007). The indoor temperature that is set for a building in the heating or cooling season is a key to the energy used in the building. There is no question that in some parts of the world buildings require heating and in other parts they need cooling to remain habitable. The challenge is to minimise the period of the year over which these systems need to be used (Nicol et al. 2012).

This study has been undertaken within the Zero Energy Mass Custom Homes (ZEMCH) research network’s demonstration project ‘ZEMCH 109’ in conjunction with the Building Environments Analysis Unit (BEAU) research centre at the University of Sheffield. The house is intended to be built in South Ayrshire, Scotland as an extension to the existing post-council and end-terraced house, namely the NRGStyle home (Fig.1). As part of the project, BEAU research centre has carried out a post occupancy monitoring of the indoor environmental conditions (e.g. indoor air temperature, relative humidity and CO₂ levels) in the Scottish affordable home as a purpose to investigate the current conditions and to run a comparison with accepted standards and guidelines. At the same time, energy consumption (e.g. electricity, gas and water) was also monitored through a smart meter in the investigated Scottish home (NRGStyle 2012).

In the study, it is therefore important for the successful demonstration of the ZEMCH 109 project that a detailed monitoring and a post occupancy evaluation (POE) are performed sufficiently to investigate the relationship between energy consumption and the indoor environmental conditions. Moreover, the results are cross-checked with the UK’s Chartered Institution of Building Services Engineers (CIBSE) guidelines and also assessed as to the range of winter internal temperatures in living space and two bedrooms in consideration of the thermal comfort criteria, as well as the relative humidity levels with the acceptable range for relative humidity levels (i.e. 40 to 70%), which is specified by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). In addition, IAQ analysis has been carried out using CO₂ data gathered whilst the energy consumption figures are collated. Table 1 describes the type of building, home age, dwelling tenure, window type, ventilation method, cooker type and number of occupants, and their ages of

Figure 1. NRGStyle home, South Ayrshire, Scotland, UK.
the NRGStyle home in South Ayrshire, Scotland (Table 1).

The aim of the study is to investigate whether the indoor environment variables comply with the standard guidelines and to find out if ventilation is correlated to the indoor temperature, i.e. CO2 vary with increase or decrease of indoor temperature, and to investigate if gas and electricity consumption correlate to indoor air temperature profile.

**Methodology**

Indoor air temperatures and relative humidity levels were measured in the NRGStyle home using HOBO U12-012 and U10-003 data loggers. Indoor carbon dioxide levels were also recorded in the same pre-refurbished home using Telaire 7001 CO2 meters (Fig.2a). Although CO2 is not toxic, it is commonly used as an indicator of air quality; high levels of CO2 indicate inadequate ventilation in a space. Both HOBO U12-012 data logger and CO2 meter were placed in the living room in the home, specifically in the breathing zone of a person sitting on a sofa (approximately 1.2 metre above the floor) and away from open windows. In addition, participants were requested to behave as normal within their homes during the monitoring period in order to obtain realistic data. HOBO U10-003 data loggers were placed in the selected two bedrooms in the house (Onset 2012).

The objectives of monitoring indoor air quality were to gain an insight into conditions within residents’ home and to compare indoor environmental conditions i.e. air temperature (°C), relative humidity (RH) and carbon dioxide (CO2) to accepted standards and guidelines. Average levels of each variable were collected in 15-minute intervals over a 24-hour period for periods of two weeks. On the other hand, the energy consumption (gas and electricity) and the water usage in the NRGStyle home were collected via an installed smart meter, Ewgeco. Ewgeco is a device (smart meter) that monitors gas, electricity and water consumption in a house. Displaying the usage may contribute to increasing the family’s awareness of housing operation patterns; thus, it may somewhat help reduce energy bills through the users’ energy-saving behaviour (Ewgeco 2012) (Fig.2b). The device was installed in NRGStyle’s existing house which is located next to the expected ZEMCH 109 construction plot. The energy and resource usage has been monitored since August 2011 and for the purpose of this study, the data from the month of December 2011 has been collated and analysed.

**Results and Discussion**

In order to investigate the indoor thermal condition and air quality, and to compare them with standard guidelines in the NRGStyle house, data were collected from the indoor monitoring equipment and statistically analysed (Fig.2). Below is a summary of the findings in the monitored home which are demonstrated through a series of graphs and descriptions respectively.

Table 1. General description of NRGStyle home in South Ayrshire, Scotland, UK.

<table>
<thead>
<tr>
<th>Description</th>
<th>NRGStyle Home</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of building</td>
<td>End-terraced house</td>
</tr>
<tr>
<td>Home age (yr)</td>
<td>44</td>
</tr>
<tr>
<td>Dwelling tenure</td>
<td>Owner occupied</td>
</tr>
<tr>
<td>Window type</td>
<td>Fully double glazed</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Natural – at least one window open every day</td>
</tr>
<tr>
<td>Cooker type</td>
<td>Gas</td>
</tr>
<tr>
<td>No. of occupants and ages</td>
<td>4 (2 Adults under 60 and 2 Children over 11)</td>
</tr>
</tbody>
</table>
Figure 3 shows the daily mean indoor air temperature (°C) of the living room and the two bedrooms for one week (16/12/2011 to 23/12/2011). The dashed line in Figure 4 is the internal air temperature of 22°C recommended in living room and 18°C recommended in bedroom. In comparison with the standard guidelines, it is clear that the living room did not comply with the CIBSE recommendation for the range of internal temperatures (22-23°C). The two bedrooms comply most of the days for the standard guideline of internal temperatures (17-19°C).

Figure 4 shows the average relative humidity RH% for the living room and the two bedrooms. The optimum level of humidity should be between 40-70% (CIBSE 2006). It can be seen that the living room agrees with the standard guidelines and the two bedrooms agree with the standard guidelines all the time during that week (16/12/2011 to 23/12/2011).

The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), a building technology society recommends that carbon dioxide levels should not exceed 1000 ppm inside a living space (ASHRAE 2012). The reason to use ASHRAE as CO₂ standard guideline is that there are no UK carbon dioxide standards for indoor air quality. However, CO₂ is
not toxic and it is used as a guide to whether or not a space has a sufficient quantity of fresh air.

Figure 5 shows the indoor CO₂ levels of the living room for one week. It can be seen that the level is fluctuating under the recommended value for indoor space (ASHRAE 2012), which indicates the availability of fresh air indoors at all the time in the living room. The three peaks indicate that there is a lack of ventilation during night time due to closing windows at that time.

To find out if CO₂ level is correlated to indoor temperature; both the daily indoor air temperature and the daily CO₂ level were correlated, and the results were statistically significant ($r = 0.35$, $P < 0.05$). Figure 6 shows this direct and positive relation. These results may indicate that the warmer space has lack of air ventilation rates and
therefore the CO₂ levels are higher, and it also reflects the dilemma of achieving proper ventilation and indoor thermal comfort. Thus, people tend to be not opening windows for fresh air to save money.

Day (22/12/2011) was chosen to plot indoor temperature against gas energy consumption for that day. Figure 7a shows the indoor temperature of the living room is not affected by the change of gas level consumption. Monthly indoor air temperature and monthly gas consumption were correlated with statistically significant results \( r = -0.66, P = <0.05 \). Figure 7b shows this direct (positive) relation. The results indicate that the higher the gas consumption the higher the indoor air temperature gets. In other words, the gas is consumed to raise the indoor temperature through the central heating.

Again, the same day (22/12/2011) was chosen to plot indoor temperature against electric energy consumption for that day. Figure 8a shows the indoor temperature of the living room is not affected by the change of electric level consumption. Monthly indoor air temperature and monthly electric energy consumption were correlated with statistically significant results \( r = -0.15, P = <0.05 \). Figure 8b shows this inverse relation. The results indicate that the higher the electric energy consumption the lower the indoor temperature is. This result should show the opposite that the higher the energy use the warmer the dwelling gets due to the casual heat gains from lighting and electrical appliances (Refaee and Altan 2012).

**Conclusions**

This study aimed to investigate the indoor environmental conditions and to compare with standard guidelines, i.e. air temperature, relative humidity and CO₂ levels of the NRGStyle home in South Ayrshire, Scotland, UK, before refurbishment (ZEMCH 109 project). The results were cross-checked with the UK’s CIBSE guidelines and were assessed as to the range of winter internal temperatures in living space and two bedrooms in consideration of the thermal comfort criteria, as well as the relative humidity levels with the acceptable range for relative humidity (i.e. 40 to 70%) specified by the US’s ASHRAE guidelines. In addition, indoor air quality analysis has been carried out using CO₂ data gathered whilst the energy consumption figures were correlated.

In this study, the indoor environmental conditions have been monitored in the NRGStyle home with comparison to the standard guidelines (CIBSE & ASHRAE) and it was observed that the living space did not comply with the range of recommen-
dation levels of internal temperatures (22-23°C), however in the two bedrooms, the standards were somehow achieved (17-19°C). On the other hand, the average relative humidity for the living room and the two bedrooms complied with the standard guidelines at all times during the sampled week (16/12/2011 to 23/12/2011).

With regards to the CO₂ levels in terms of IAQ, it was seen that the levels are fluctuating under the recommended value (1000 ppm) for indoor spaces (including living and bed rooms), which also indicated the availability of fresh air indoors at most times in the sampled week with an exemption of the three peaks indicating a lack of ventilation during night times due to closing windows at that time.

When the indoor environmental conditions (indoor air temperature and daily CO₂ levels) were correlated with statistically significant results, the findings have shown a direct and positive relation indicating that the warmer space has lack of air ventilation rates and therefore the CO₂ levels are higher, and reflecting the dilemma of achieving proper ventilation and indoor thermal comfort. Moreover, the indoor environmental conditions (indoor air temperature and a random day gas and electric levels of consumption on 22/12/2011) have been correlated with statistically significant results where the findings have shown the indoor temperature of the living room is not affected by the change of gas level of consumption, indicating a direct and positive relation. In contrast, even though the results against electric energy consumption for the same day were shown the indoor temperature of the living room is not affected by the change of electric level of consumption, which is indicating an inverse relation.

The correlation analyses have shown both direct and inverse relations, highlighting the energy demand is prone to be mostly proportional to indoor air temperature and CO₂ levels, i.e. housing energy demand for space heating increases when the indoor air temperature and CO₂ levels decrease or vice versa. Furthermore, to complete the analysis, it would be also necessary to carry on with further studies into environmental control and human behaviour in the NRGStyle home, as well as undertaking a post occupancy monitoring after refurbishment has taken place to compare the pre and post indoor environmental conditions and to correlate against the energy consumption levels.
Acknowledgement

The authors would like to express their sincere gratitude to CIC Start Online for the financial support and equally to Dr Branka Dmitrijevic, Director, for her constructive guidance on the grant application. Also, we would like to thank deeply Mr Norman Smith and Ms Alison Quinn, NRGStyle Ltd, for the provision of the construction site documents and the company’s aspirations accompanied by their patient and effective collaboration.

REFERENCES


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Social Rental Housing in South Africa is to some extent based on Dutch precedents, thus the films in part, become an investigation into the possibility of government investment in social housing by developing “base buildings”, allowing for multi-skilled teams to provide the “infill” – possibly achieving long-term sustainability of the housing stock, better return on investment with regards to government subsidies and allowing for more involvement of users in the decision-making process.

This alternative design, delivery and procurement approach would allow for adaptation of rental housing to achieve income generation activities as well as different family configurations and alternative lifestyles.

The movies therefore intend to start a conversation in the application of the concepts of Open Building in the South African housing context.

In the Netherlands, the focus is on presenting and commenting on past and recent projects as relevant case studies to extract the positive qualities as well as the difficulties dealt with during the realization of the projects.

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Book Review

Book Title: CLIMATE CHANGE ETHICS – Navigating the Perfect Moral Storm
Author’s Name: Donald A. Brown
Publisher’s Name: Earthscan from Routledge
Reviewer’s Name: Yonca Hürol, Eastern Mediterranean University, Cyprus.
Dimensions of the Book: 15 x 23 cms
Hard or Soft Cover: Soft
Number of Pages: 271
Order Address: www.earthscan.co.uk (and for price)
Number of Illustrations: 10 charts and tables.

KEY WORDS: Climate change, ethics, policy making

Climate change is a subject with which many professions are involved. Donald A. Brown, the author of this book called “Climate Change Ethics – Navigating the Perfect Moral Storm,” is an environmental lawyer who also worked on climate change as Program Manager for UN Organizations in the US EPA Office of International Environmental Policy.

Brown says that climate change is the greatest environmental and social threat facing the human community. The objective of his book is to examine priority ethical issues in relation to climate change and to make recommendations on making ethical considerations influence policy formation. According to Brown, climate change must be understood as a moral problem, because many policy issues which need resolution to achieve a global solution require looking to ethical principles for their solution. The book achieves its objective by introducing thirty-five years of climate change policy debate, by discussing all ethical issues in relation to climate change (including cost arguments, scientific uncertainty arguments, national emissions targets, adaptation costs, obligations of subnational governments, organizations, businesses and individuals and independent responsibility to act) and by showing the crucial role of ethics in climate change policy making.

“...For climate change is a problem that, if not controlled, may cause the death of tens or hundreds of thousands of helpless victims caused by intense storms and heat waves; the death or sickness of millions that may suffer dengue fever or malaria; the destruction of some nations’ ability to grow food or provide drinking water; the devastation of forests and personal property; and the acceleration of elimination of countless species of plants and animals that are already stressed by other human activities...” (p.126)

“One cannot say, of course, that human-induced climate change is the sole cause of those events, but rather that climate change makes these events more probable, and, that statistically extreme weather events are increasing in frequency...” (p.217)

The book also shows that there is an ethically flawed and ideological disinformation campaign. According to Brown, climate change ethics should be introduced to people and a worldwide social action should be created in order to force formation of a powerful policy against climate change.

The book is useful for everybody who wishes to know more about climate change, its history and the political truths about it. It collects a large amount of knowledge and information with the help of an understandable and clear language. The book has a large reference list and an index.
BOOK REVIEW

by Dr. Jia Beisi,
Department of Architecture, The University of Hong Kong.

Although experimental buildings have been built around the world, the difficulties of implementation on a larger scale prevail. Only a few efforts have been made to organize the knowledge and to formulate the implementation strategies for the builders and designers. The research on flexible buildings address the technical components, but the possibility of integration with the current housing market is overlooked. Thus, this book is a significant contribution in the effort to fill the gap “between theories pertaining to flexibility and the reality of housing market” not only for North America, as the author explained, but also for the rest of the world. The publication of the book is a significant addition to the literature on flexible housing.

The objectives of the book are premised on the understanding that flexibility has not been generally accepted in North America because of the problems of implementation. It intends to develop a project based decision-making model to assist designers and builders in determining the relevant level of flexibility which is best fit to their particular projects.

The book is informative and serves as a conceptual instrument for the housing decision makers, including governmental housing organizations, private housing developers and builders, designers, and other promoters who want to design flexibility projects. It is useful for programmers, housing researchers, and students of architecture and building management. It can provide inspiration to residents and the general public who are interested in new living styles as well as in benefits from monetary savings and better living standards during their residency.

Selected keywords: Flexibility, implementation, strategies, economics, alternatives.
This groundbreaking book is a new comprehensive round of debate developed in response to the lack of research on design pedagogy. It provides thoughts, ideas, and experiments of design educators of different generations, different academic backgrounds, who are teaching and conducting research in different cultural contexts. It probes future universal visions within which the needs of future shapers of the built environment can be conceptualized and the design pedagogy that satisfies those needs can be debated.

Addressing academics, practitioners, graduate students, and those who make decisions about the educational system over twenty contributors remarkably introduce analytical reflections on their positions and experience. Two invited contributions of N. John Habraken and Henry Sanoff offer visionary thoughts on their outstanding experience in design pedagogy and research.

Structured in five chapters, this book introduces theoretical perspectives on design pedagogy and outlines a number of thematic issues that pertain to critical thinking and decision making, cognitive and teaching/learning styles, community, place, and service learning, and the application of digital technologies in studio teaching practices, all articulated in a conscious endeavor toward the betterment of the built environment.
32 years of back issues. Available on DVDs as well as on-line. This digital collection consists of 128 issues with approximately 1,024 articles dealing with settlement, planning and housing design, education, adaptability, open building, sustainability, affordability, user participation, design roles and many other aspects of housing and settlement design. Many case studies from around the world are included. Open House International is covered by EBSCO Publishing Thomson ISI and Elsevier Scopus databases.

University References:

"One major contribution of Open House International is its ongoing emphasis on open-ended design as an important attribute of environmental quality of built environments. Through this, Open House International has ensured that this topic has not been forgotten and has continued to develop." Prof. Amos Rapoport, University of Wisconsin, USA.

The high academic level of the journal is an example to be followed. We are privileged by our affiliation with you and the journal. I think that our disciplines are hungry for the level of academic rigor that OHI demonstrates on a sustained basis."Guillermo Vasquez de Velasco, Dean, College of Architecture and Planning, Ball State University.

"Open House International provides a unique, international forum for presentations of the multi-dimensional nature of housing with illustrative examples from all continents around the globe. Today this perspective is rare in mainstream academic and professional publications." Dr. Rod Lawrence, University of Geneva, Switzerland.

"This is a journal with a long standing history of exploration into issues of development, built environment and housing. It distinguishes itself in the unselfconscious way it invites writings reflecting people, work and thinking not yet part of the mainstream." Prof. Nabeel Hamdi, Oxford Brookes University, Oxford, Great Britain.

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"Since its beginning in 1976 Open House International has been the only journal to cover the extremely important ground between the traditional and the "new" concerns of architects and builders and those of development studies. This is of increasing significance in the context of the international agendas for the next millennium." Prof. Pat Wakely, Prof. Emeritus, Development Planning Unit, University College London, UK.

Among the journals focused on the built environment Open House International (OHI) has always stood for the possibility of informed discourse on cross-cutting, global and local issues linking methods, the culture of building, built form studies, technology, pedagogy and user-centred public policy and planning. Thank goodness it is there for students, teachers and practitioners." Prof. Stephen Kendall, Ball State University, USA.

"...In recognition of the high quality and relevance to the scientific community of Open House International we are pleased to inform you that your publication has been selected for coverage in the Elsevier Bibliographic Database Scopus as of 2007.

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