Paper no.175: Environmental Architecture. Parametric Design and Users' choice.

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Abstract

This paper presents the initial results of my research-by-design into parametric, prefabricated, high-density low carbon dwelling typologies that allow for both user choice and a privatised relationship with some version of a 'garden'. Parametric design is a rule-based methodology that in this case allows future residents to assemble their dwelling with the constraints of the kit of parts and optimised environmental performance. User participation is as key to this system as high environmental performance.

The architecture is thus generated by the rules and by user choice. The kit of parts contains elements that allow waste recycling, cultivation of crops and rainwater harvesting, in an attempt to positively influence the lifestyle of the users. The use of prefabrication would deliver lightweight buildings, allowing greater space for the rationalization of resources, lower consumption of energy and the installation of prefabricated building components that utilize fewer resources compared to traditional building techniques This paper investigates the industrial logic with which prefabricated building components are produced, the reason for the need of user's participation in the building process and tools to enable this participation.

Keywords: MMC, Parametric Design, Sustainable Communities

1. Introduction

This design-led research investigates possibilities for developing low energy neighbourhoods through a process of participation of the users. The investigation encompasses three areas:

1. self build, self-procured dwellings;
2. use of high performance prefabricated components for low carbon residential buildings;
3. use of parametric design.

Trend projections**,** in the UK show an increase of self-build houses.

'First-quarter figures from BuildStore, supplier of finance, materials and advice to people who want to build their own homes, show mortgage applications rose almost 70 per cent to £178 million in 2005.' [1]

Industry in this area has potential for producing a high variety of customized components that can generate a variety of building types and finishes.

The project investigates how parametric design can enable users to generate low carbon buildings and neighbourhoods through a prefabricated kit of parts and a set of rules that binds users and at the same time gives them high flexibility. This paper looks into each one of the above mentioned areas before illustrating the final design research.

2. Prefabrication and Modern Methods of Construction.

2.1 Historical references.

Early prefabricated building elements and processes stem from the rationalist dream of architecture as a product.

Le Corbusier wrote in 1923:

'There exists a new spirit. Industry, overwhelming us like a flood which rolls on towards its destined end, has furnished us with new tools adapted to this new epoch, animated by a new spirit.

*(…)*We must create the mass-production spirit:

The spirit of constructing mass-production houses. The spirit of living in mass-production houses. The spirit of conceiving mass-production houses.' [2]

Forty years later, technology and market demand realised this vision. During the 60's and early '70's prefabrication became a reality in the building sector everywhere in Europe. Unfortunately, rather than generating affordable, high quality dwellings for the many, the industrial production of building elements created standardization and monotony where it should have allowed a greater freedom and higher quality standards for designers.

Industrialization embedded repetition. The use of repeated elements as a design parameter was explored at the Bauhaus. Walter Gropius saw prefabrication as the way to build large numbers of dwellings in a fast and effective way, and in the 1920's and 30's, the first industrial homes were seen as a symbol of modernity and progress. [3]

As R. B. White pinpoints, during the first half of the XX century Sweden and Germany together with United States succeeded in developing a market for prefabrication in response to house shortage and war destruction. In UK this did not happen although UK Government, following several commissioned reports, sponsored experiments in prefabrication, some of which were interesting. However, endeavours did not have the necessary impact on the market, maybe because prefabrication was envisaged as a short

term answer to emergencies and not as a long term investment. [4]
However, in the 60's, because of an extreme shortage of housing and a lack of experience in harnessing industrial processes, the true potential of prefabrication was never fully exploited. It may be said that manufacturing efforts were directed to mass production both of homes and products to fill them, responding to a budding market that was anxious to possess a share of welfare**.**
Industrial processes nowadays have been digitalised, allowing the development of 'mass customization' of building components. CAD/CAM (computer-aided design/computer-aided manufacture) is the most advanced example of this technique, used by Frank Gehry to make his design of the Guggenheim, Bilbao affordable [5]. This customisation reflects the contemporary promotion of individual consumer choice. Prefabricated house companies such as the German WeberHaus or the Swedish Ecothech maintain the differentiation of the components as an essential feature of their production and a highly personalised product gives a competitive edge in this market.

2.2 Customised contemporary prefabrication.
The prefabricated house market has expanded in the last twenty years. Prefabricated houses are basically built out of a kit of parts with a high potential for customization and, sometimes, transformation over time. This is due to evolved industrial processes and machinery able to make the individualization of each single component produced economically viable. Prefabricated house kits generally utilize either timber frames or low density concrete elements with bricks, or steel.
In the UK and abroad there are now excellent examples of prefabrication with real architectural quality. As if to mark this step-change, there has been a change in name from prefabrication to, Modern Methods of Construction (MMC).
Designers are learning how to harness industrial logic and to assemble creatively a kit of parts. What is more important, some companies prefabricating houses are currently committed to delivering affordable, energy-efficient houses.
Companies like Ecotech (Sweden) offer systems with a high degree of flexibility (Fig. 1) that can meet Levels 4,5 & 6 of the Code for Sustainable Homes [6]. The PlusEnergie house, produced by German company WeberHaus, claims to produce more energy that it consumes [7]
Companies in this area offer a differentiated range of products that meet any market niche

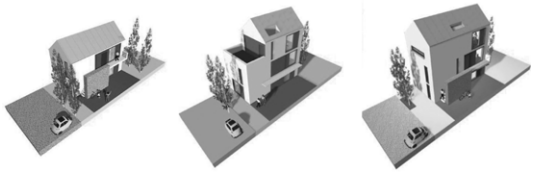

Fig 1. Ecothech – Sweden. Flexible system with a large number of variations, that meets Code for Sustainable Homes standards

Fig 2. EnergiePlus – Weberhaus. German prefabricated house that produces more energy than it needs.

demand and are often extremely competitive if related to the cost of traditional constructions.

2.3 Environmental benefits related to prefabrication.
SmartLife, a EU financed program to facilitate sustainable growth, in a recent study on MMC states: 'In the UK, MMC is broadly seen by the Government as part of the solution to the mass housing shortage. It is seen as cost effective and a faster method of construction. It is acknowledged that MMC can provide a more environmentally-preferable solution to construction as well as, for example reducing waste, defects and transport to site.' [8]
Modern methods of construction (MMC) have environmental benefits if compared to traditional building technologies. MMC aims at a minimisation of resources and labour time on site. The factory environment allows a greater efficiency and precision and a rationalisation of waste disposal.
Precision and accurate detailing translates into high performance of the finished product and this is essential in order to achieve energy efficient buildings with less embodied energy. Presently there is no exhaustive research that allows a detailed environmental comparison of MMC with traditional building techniques: site conditions and a large variety of cases would require a very complex analysis.
Commissioned by the UK Government, the Callcutt Review, looking at the house-building industry's structure and business model, states that although critics of MMC point out the considerable up-front investment needed, if compared with traditional methods, 'MMC potentially offers faster construction, cleaner and safer working environments, fewer housing defects, reductions in construction waste and improvements in energy efficiency of the home in use.' [9]
However, it is essential that 'prefabrication occurs as locally as possible to minimise the environmental impact of transportation. (…)Systems should be selected that can be readily reused or recycled.' [10]
Therefore, given a rational and responsible use of the supply chain, MMC has some advantages

over traditional building techniques in terms of waste and energy efficiency. Given the pressure that waste is exerting on the environment, and the compelling necessity for a rationalisation of resources, MMC is a viable direction to explore.

3. Empowering individuals and communities.

3.1 Demand for self build

'UK Government plans to build 140,000 extra homes a year to keep up with demand. Estimates say there are between 220,000 and 230,000 new households being formed annually, and only 165,000 homes being built**.** The UK also has a large speculative market: with approximately 79% of new homes being provided by developers, 13% of homes are built for non- or limited-profit organisations and 8% are self procured. In contrast to Sweden and the UK, Germany has a much larger self-procurement market, constructed by their eventual occupants either directly or through subcontractors, and accounting for 55% of production. Speculative developments in Germany account for only 32% and social housing is about 13%.' [11]

UK home-owners' attitudes and cultural backgrounds are barriers to an expansion of the self-build sector, but the difficulties related to self-procurement and the improvement of a poor market offer in this country should not be underestimated. If self-build can be an important factor in delivering the necessary housing stock, how can demand for it be boosted? What can trigger a positive loop between the raising of demand and the increase in, and diversification of, the offer?

As the Calcutt review emphasises, self-build is an important alternative for the building industry, which is currently unable to deliver the necessary numbers of planned housing stock. What are the necessary steps to stimulate the interest of new home owners for the self build?

3.2 Enabled Self Procured Simulation.

The 'Enabled Self Procured Simulation' (ESP-SIM) is one of several projects funded by the UrbanBuzz, 'a two year evidence based programme, designed to share knowledge, stimulate new thinking and bring the ideal of building sustainable communities'. [12]

Esp-sim is a project that aims at stimulating self build by connecting stakeholders through their website and by providing them with effective tools: : 'Firstly, through our blog, we hope to engage the views of various stakeholders and decision makers in the planning and regeneration sectors. (…)Secondly, we are building multi-user on-line software which will simulate the consumer experience of entering an enabled self procured project. This software, called *YouCanPlan,* offers future residents a choice of plots within a community, and a range of preapproved house design choices to design their own customised house.' [13]

In short, homeowners are empowered to select an available site, compose their homes through the 'kit of parts' contained in the software and through this web-based community, be in touch with local authorities for building permission, and with developers for help with infrastructure and self-procurement. Local authorities make sites available for development; developers supply infrastructure and an initial master plan, home owners choose their plot, compose their house and look at what is already being designed by other future inhabitants of the area.

The software is based on 'pattern books' designed by several designers, each one containing a series of architectural elements that, once assembled, can be visualised on line and modified by the users.

Designers of each pattern book are required to give particular importance to MMC. Products used should be available in the UK market or should be based on UK market potential. Expectations are that if this experiment is successful, the industry will become more cost-effective, more efficient and more proactive. The experiment, currently under development, is a clever attempt to connect current governmental policies, economic requirements and people's needs. It is still unclear the degree of interaction between the stakeholders (local authorities, developers, home owners). However, this web based community could potentially become a strong tool for participation if future inhabitants are allowed to voice their opinion on infrastructures and services of the development.

It is desirable that such a powerful tool generates energy-efficient dwellings to foster sustainable communities, and separates the greater economic and environmental efficiencies of prefabrication from its previous connotations of monotony and poor quality.

3.3 Sense of place and communities

Several studies on sustainable communities have tracked parameters that are key to peoples' wellbeing and to a successful built environment. The CABE report 'Sense of Place' analyses people's aspirations in terms of dwellings, and how these aspirations are met – or not - in reality. 'Buyers are often constrained by both the availability of suitable homes in high-quality developments and by practical constraints on where they can live and what they can afford. (…) High costs and low standards are at the roots of people's dissatisfaction about the place they live in. Where there is dissatisfaction there cannot be any sense of place or sense of community.' [14]

The market offer is short of high quality affordable dwellings and self build could be a solution.

Participation is arguably an important factor in the creation of sustainable communities. Involvement in the process of creating a personalised built environment can trigger an awareness of belonging to a community. The process of self-procurement actively depends upon consumer involvement, as it is 'by' as well as 'for'. Tools and conditions can enable people to achieve houses built to a good standard, designed according to each owner's needs and desires, at a competitive cost, with design and building process being personally directed with no mediation

But what is an appropriate design tool that allows a kit of parts to be efficiently managed by users that have no knowledge of design processes? And how can this design tool produce a diverse and rich environment if utilised by people who have little knowledge of design processes?

4. Parametric design

'Parametric design (…) is a method that can, in whole or in part, define the design process.' [15] Parametric models allow the user to set up a hierarchy of relationships that can be defined rules, in which the whole adjusts and changes when a rule is modified. In short a group of elements interacting according to a set of rules can trigger a generative process in which the elements will be deployed in always different fashions. This fractal logic is highly appropriated for computer processes but parametric design can also be performed manually.

Can parametric design be applied to MMC and generate built environment with high environmental performance?

Parametric design has been widely used in Environmental design. In a way Ian L. McHarg has pioneered the parametric logic in his multilayered processes in which environments were mapped and redefined according to environmental rules and parameters.

Established rules encompass site conditions, targets given by the initial brief or anything that is essential to any given context.

At best, prefabricated houses sell a kit of parts that can be assembled in a wide variety of shapes and finishes. Buyers select the most suitable shape or format according to their personal taste and needs.

What if the kit of part can be assembled only through binding rules and these rules embody essential conditions to shape dwellings with a high level of environmental performance, essential features for a building a better environment and a high level of differentiation in the building fabric?

The project this paper introduces investigates this subject.

5. Design through Parametric Design for Users Choice.

5.1 Introduction

What is essential to people when designing residential developments? It is assumed that the majority of people worldwide live in cities and this trend at the moment seems irreversible. As global population grows, so grows a compelling need for an urban context that is more human, better designed and more integrated with open space. This last point is particularly important. Although it essential for cities to densify their fabric, built environments require private and public open spaces.

Jules Pretty, Professor of Environment and Society at the University of Essex, has led research into measuring the degree of well-being of people that lead open air activities compared to sedentary people. Gardening, room with views or simply the presence of vegetation by the dwellings increases physical health, decreases health-related expenditure, and improves concentration at work. [16]

There is also a compelling need of each human to identify with the place he lives in. This can be achieved through a process of participation. However, these processes involve many stakeholders and require long time scales.

The design of a toolkit for home owners that is easy and fast to use can be precious and help joining all the dots while speeding up processes.

Environmental performance needs to be at the core of the toolkit, as well as rules that can improve the well-being of communities and standards of design for prefabricated dwellings.

In my design of a pattern book, I made certain decisions in keeping with these aims:

A - high densities of dwellings per hectare; B – open space attached to each dwelling; C – kit of parts with a high degree of 'embedded' environmental features; D – use of low embodied energy materials; E – flexibility that allows high level of customisation and modification over time.

5.2 Parameters.

My 'kit of parts' is designed to deliver self build dwellings in a constantly varied fashion. Each user's choice in composing his/her dwelling within the elements of a flexible abacus, combined with the constraints given by the set of rules, will automatically determine a varied configuration for each building.

Flexibility is made possible by the industrial processes that lay behind MMC.

The kit of parts delivers lightweight buildings designed according to Passive Solar principles. Each dwelling would have interior finishes with high thermal mass, the choice of a wide window that could be plugged in as a sun-space, and, wherever possible, orientation to provide sufficient solar gain.

Though my design rules encourage high densities in each development, it is possible to mix typologies to provide a choice of single house, terraced house or flat, in the interests of creating a mixed community. (Fig. 3)

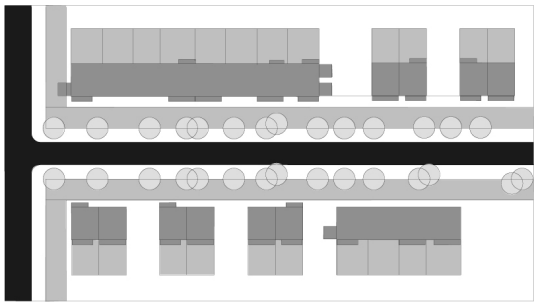

Fig 3. Single houses, semidetached houses and block of flats of different sizes in different possible configurations.

Space heat through direct solar gain is encouraged. However, is up to the dwellers to

choose among an array of energy efficient possibilities, and the orientation of their dwelling will obviously be a contributing factor. They can select the sun space from the kit of parts or decide that energy should be supplied partly through renewables and partly through a district CHP power station. The power station is part of the infrastructure supplied by developers, while renewables can be plugged into the roof of the building.
Single dwellings plug into a structural skin. The structural skin contains fixed vertical circulation and bathrooms. Users can compose their dwelling by selecting the number and sizes of rooms they want. Rooms are built off-site, each one already provided with appropriate insulation and necessary cabling and plumbing.
Once rooms are inserted in the structure, external cladding on panels**,** additional insulation and windows are added.
Cladding is varied and the composition of the façade is therefore also varied, as a result of the user's choices of finishing materials and number and size of rooms. (Fig. 4)

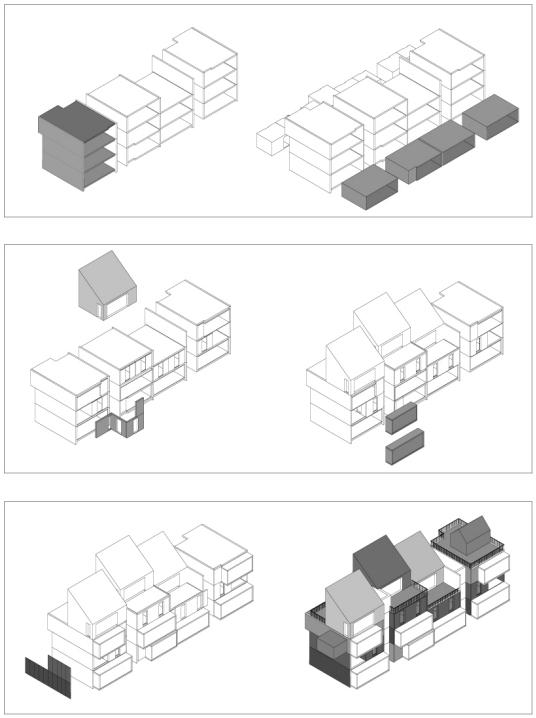

Fig 4. Diagrams representing the several stages of assemblage.

To save energy and money, no lifts are provided; consequently the building block is limited to three or four storeys.
This system allows dwellings of every size: from studio flats to three bedroom flats, and includes also maisonettes with pitched roofs on top floors (Fig. 5). The roofs themselves are used for PV panels and evacuated tubes.
A binding rule is that each dwelling has an open space attached either as a garden, balcony or terrace. Open air life is encouraged as well as a small cultivation of crops on terraces and roofs. Each building is equipped for rainwater harvesting and grey water recycling. Composting facilities and living machines are integrated in the general planning.

Fig 5. TOP: one of the possible configurations of a block of flats. A private open space is attached to each unit. BELOW: Some of the possible configurations of single dwelling.

5.3 Kit of parts and set of rules
The construction materials specified have low embodied energy and come from sustainably managed sources: A. Superstructure in engineered cross laminated timber. B. Rooms made of SIP insulated panels. The room size is modular and can expand or reduce in one direction. In doing so, facades modify over time.
C. External cladding mounted on cross laminated panels in different finishes: timber tiles, clay tiles, slate. D. Sun space composed with a frame of cross laminated engineered timber, timber frames and double glazing. The sun space is provided with automatic exterior curtains that shade from the sun in the hot months. E. Greenhouses that can be attached sideways or mounted on the roof**.** The structure is composed with timber profiles. G. Selection of finishing materials for interior with high thermal mass. Interior walls and floors are clad with light concrete tiles of several colours and sizes. Clay tiles are mounted below timber beams at ceiling. (Fig. 6)
Homeowners, when selecting the size and shape of their dwelling would be required to follow the design-generating rules:
Rule a.
Each dwelling is composed from a kit of parts with embedded environmental features that can be combined into a variety of sizes, from studios to maisonettes to houses.
Rule b.
The kit of parts is prefabricated.
Rule c.
Each user selects their desired combination of parts and 'plugs in' the unit to the building block.

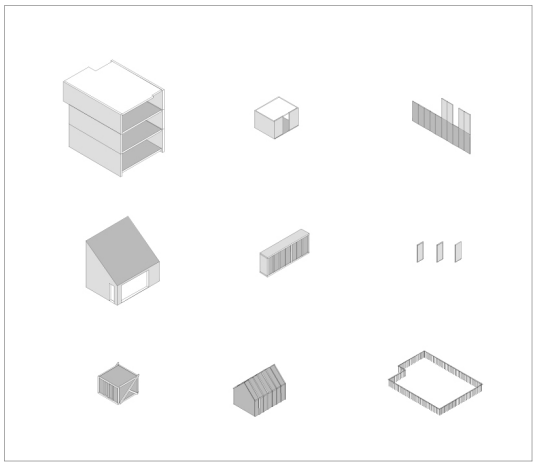

Fig 6. Abacus of elements

Rule d.
Each user selects an appropriate terrace, green roof, garden and/or greenhouse .
Rule e.
Environmental and passive solar features determine the orientation of the building and the distance between buildings.
Rule f.
The relationship and distance between buildings generate public spaces that favour casual encounters and a sense of place.
This represents only a summary of the possible set of rules and there is little doubt the rules, kit of parts and general conditions of interaction of the several parties need to be investigated further but a first hypothetical deployment demonstrates the potential of environmentally-led parametric design for user choice. (Fig. 7-8)

6. Conclusions

The growing trend in the UK for the self build. is being stimulated by the current housing shortage. This in turn could stimulate manufacturers to develop products for the self build market, one of the most promising of which is the prefabricated kit of parts. This type of production is popular in Germany, Sweden and France, and UK has the

Fig 7. View of the development of self build dwellings.

potential and the know-how but currently lacks the demand. It is difficult to predict if the recent economic downturn and the subsequent housing market crisis could discourage the self build market. On the one hand, economic advantages

Fig 8. Façade varies according to the single choices of material for cladding and configuration of dwelling.

on traditional methods of construction could result attractive to home buyers; on the other hand, since UK production of prefabricated house systems is lagging behind, it may be difficult for companies to plan substantial investments in this field without any public intervention.
MMC with current technologies can produce highly differentiated and customized kits of parts. As high quality dwellings and environments, and participation in the development process, are necessary for the creation of sustainable communities, home owners should be enabled to create built environments that reflect their needs. The right tools are key to this process: if correctly used, they can provide highly differentiated environments with a good environmental performance.

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