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SWISSWOODHOUSE, INNOVATIVE EXPERIMENTATION IN SUSTAINABLE MODULAR HOUSING : FROM INTERDISCIPLINARY RESEARCH TO POST-OCCUPANCY MONITORING

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Fig 1: View of the pilot project built in Nebikon, Switzerland

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Research summary

The Swisswoodhouse concept is the outcome of a number of studies on issues related to urban densification, structural changes in households, housing adaptability and the environmental challenges of sustainable construction. The building design is more specifically based on the aggregation of prefabricated 22 m^2 wooden modules that can be adapted to provide a wide variety of types and functions. At the technical level, priority has been given to energy issues in order to satisfy the requirements of the vision of the "2000-Watt society". Following an interdisciplinary research phase, a first building with 18 apartments was completed as an experimental prototype near the railway station at Nebikon, Switzerland. This first achievement provided an opportunity to test the overall results of the parameters developed within the research framework. At the construction level, the experiment successfully tested the prefabrication and on-site assembly processes as a whole. In terms of energy, post-occupancy monitoring was set up to provide the first indicative figures on the performances of the building.

Keywords: sustainable architecture, modular housing, integrated design, 2000-Watt society

1. Introduction

1.1. A context of urban densification

Several studies on sustainability issues have pointed to the many negative consequences of urban sprawl : land consumption, pressure on landscape, environmental impacts due to mobility, exacerbation of socio-cultural inequalities and infrastructural costs (Rey, 2013). In particular, the correlation between low density and energy consumption due to mobility has been analyzed in the works of P. Newman and J. Kenworthy on automobile dependence (1999).

Awareness of these multiple consequences has contributed to the development of territorial strategies capable of reversing the trend. Based on a better coordination between urbanization and mobility, these strategies can be seen especially in the promotion of increased population density close to public transport, enabling a reduction in automobile dependence by promoting the untapped potential within developed sites (Rey, 2012, PUL).

The development of innovative concepts of sustainable housing is part of this process to increase urban population density. As K. Williams observed, an intensification of land use is a necessary condition to reach more sustainability, but it is certainly not sufficient (2000). Strategies must indeed integrate other qualitative parameters, notably potential for inter-generational mixing and promotion of high quality of life for users. The challenge is notably to develop alternatives to individual peri-urban housing leading to a reconciliation of density and quality of life (Rey, 2014).

1.2. Facing the reduction of household size

Alongside the issues concerning housing location, the concept of sustainable development involves taking a stance for a vision of a long-term equilibrium, in particular between the built environment and socio-cultural needs. Along the same lines, recent demographic trends in Switzerland (as in many European countries) highlight two phenomena to be considered for new housing, i.e. the metamorphosis in family structures and the evolution of a population that is living much longer.

Over the last decades, traditional family structure has been strongly challenged. Households with children now only represent one third of all private households. Among these households with children, the share of one-parent families is increasing steadily. Households without children are the most common and they continue to increase in number. These households are made up of young people who have left the family home and older people, owing to the fact that life expectancy has increased.

These changes have a major impact on the size of households (OFS, 2008). The latter is steadily decreasing : fewer and fewer cross-generation families are living under the same roof and ever more people are living alone. This means that, according to statistical projections, the share of households with more than two people in 2030 will not exceed 24%. So, the majority of households will comprise either a single person (41%) or a couple (35%) (OFS, 2009).

These changes call into question current practices in terms of housing design. In fact, given the lifespan of a housing accommodation in Switzerland, a building constructed today will be faced with changing demands in the decades to come. In response to these changing socio-cultural needs, it seems relevant to plan for spatial configurations and constructive methods that offer greater adaptability in housing use.

1.3. Toward the 2000-Watt society

Another fundamental issue is the balanced management of resources, in particular the creation of optimal buildings considering the local climatic conditions, based on energy efficiency design and priority use of renewable energy. For Switzerland, this challenge resonates with the vision of the 2000-Watt society developed by the Swiss Federal Institutes of Technology. On a global scale, individual human consumption is currently in the order of 17500 kWh annually, which corresponds to a constant power of 2000 Watts. In Switzerland, current consumption corresponds to around 6300 Watts per person, across all forms of energy. The idea of a 2000-Watt society is to bring these needs down to 3500 Watts by 2050 and to 2000 Watts by 2150. Of these 2000 Watts, only 25% must be sourced from non-renewable energy sources, in order to also drastically reduce the volume of CO_2 emissions (Novatlantis, 2011).

If research carried out has stressed that such a vision is feasible in theory, considering that many potential energy savings have been identified, it has also underlined the need for continuing and convergent changes in every area of human activity : housing, mobility, food, consumption and infrastructure.

In this context, housing (room heating, hot water, and lighting) and mobility constitute the main parts of total energy consumption in Switzerland today. Designing sustainable housing is part of the energy turnaround challenge and involves a simultaneously creative and rigorous consideration of energy-efficiency issues.

2. The Swisswoodhouse concept

2.1. Density, modularity and flexibility

To confront the issues linked to sustainable territorial development, the objective is to create a new type of collective building, one that reconciles the needs for density and some of those features found in the private household, such as ways of personalizing space, the potential to change ownership and the extent of outdoor areas.

At the building level, the concept of Swisswoodhouse rests on the observation of potential for increasing population density at the core of the existing building and close to the nexus of public transport in suburban localities of built-up areas. This analysis has led to a reflection on the optimal size for such a building. The approach aims to provide an alternative to the peri-urban individual houses with a 3-4 storey high building, presenting a sufficient size to contribute to the densification process, whilst avoiding the danger of anonymity present in high-rise developments.

Fig 2: Functional module measuring 22m^2 adapting to the different functionalities of the accommodation

The building's concept is based on the aggregation of 22m² wooden prefab modules. Each module can be deployed in a wide variety of types and uses: kitchen with or without pantry; bedroom; two modules combined for a master bedroom with en-suite and built-in wardrobe; bedroom with loggia balcony; living room or patio (Fig. 2). An entire catalogue of

options has been devised, allowing for multiple combination apartments (Rey, 2012, PLEA).
The surface of the module constitutes a unit of reference that, singly or in combination, satisfies the multiple needs of very different users, encouraging a social and intergenerational mix (young singles, childless working couples, large families or the elderly) (Lüthi, 2008).

2.2. Prefabricated design building

Via its standardized basic grid, Swisswood-house offers great functional flexibility not only in the planning phase, but also during the use phase and in the event of subsequent changes in needs. However, the real degree of this adaptability is dependent on the construction methods of the building, especially the precise dissociation of the load bearing (fixed) and non-load bearing (adaptable) elements.
Architectural design has therefore integrated this aspect by developing a clear and simple principle, allowing construction in prefabricated parts, mostly made from wood. The structure of the building rests, on the one hand, on the facades made from prefabricated wooden elements and, on the other, on a central part, made from concrete prefab parts that also include all the vertical technical distribution (water, heating, electricity and ducts for controlled air circulation). The slabs are designed in a hybrid manner, including concrete parts in the wooden prefabricated pieces, which can meet high acoustic requirements.
Technical installations follow the same logic and are designed to be integrated into the construction elements and be mostly prefabricated. Secondary elements complete the catalogue of modules that make up the apartments, notably a system of balconies that aims to offer several kinds of outdoor space. The latter are designed in such a way that they can be fixed to the façade subsequently. Concerning the stairwells and lifts, these are also part of the surface area corresponding to one of the modules.
The abundant use of wood offers several benefits to meet the high targets in terms of sustainability. On the one hand, wood resolves certain construction details in the simplest way by removing some of the thermal bridges in the joins between vertical and horizontal elements. Furthermore, regarding embedded energy, this approach allows recycling of an abundant local resource that is currently underexploited in Switzerland. The result is a reduction in environmental impacts as much in terms of non-renewable primary energy (NRE) as in equivalent CO_2 emissions.

3. Pilot project in Nebikon

3.1. First real experimentation

Following the interdisciplinary research phase, a first pilot building, a prototype, was constructed in the Luzern commune of Nebikon, in Switzerland (Guntern, 2014). This initial construction enabled verification of the feasibility of initial hypotheses and actual experimentation of the operational issues involved in an architectural concept such as this.

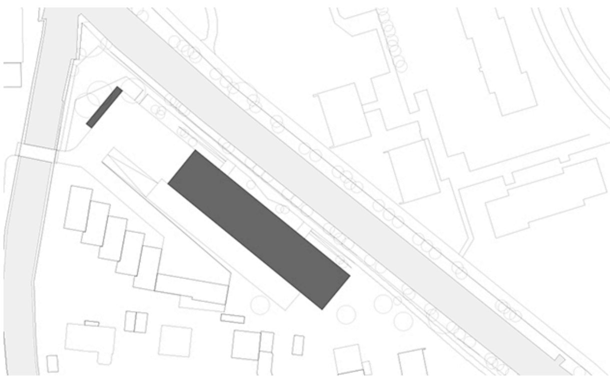

Fig 3: Location plan of the pilot building in Nebikon

The aim was to densify a plot of land with very good public transport services, located near the railway station (about 5 minutes on foot), and near a river (Fig. 3-4). The chosen configuration for this pilot building is a 3-floor rental property with a loft and a total of 18 various types of dwellings (Table 1).

Fig 4: Exterior view of the pilot building

With the exception of the stairwells, which were cast in reinforced concrete on the spot, the ensemble was entirely prefabricated and then assembled in-situ. The 4-level building was thus mounted in less than one month.

Data	Values
Length	60 m
Width	13 m
Energy reference area	2,525 m2
Total number of flats	18
2.5 rooms	4
3.5 rooms	2
4.5 rooms	8
5.5 rooms	4
Building permit	May 2012
Construction to commence	September 2013
Assembly on site	March 2014 (3 weeks)
Operational	October 2014

Table 1. Essential data of the pilot building

With their different layouts, the 2.5- to 5.5-room dwellings reflect the multiple possibilities of the architectural concept. The apartments' key features of are their original spatial layout, the diversity of their visual interaction with the environment, their high flexibility of use and the quality of the exterior space arranged as loggias or terraces (fig. 5).

Fig 5: Interior view of a flat in the pilot building

3.2 Energy efficiency and ecological issues

To meet the targets of the 2000-Watt society, specific studies have allowed for the share of energy specifically available for housing to be estimated (materials, heating, electricity and inferred mobility) at 840 Watts per person over a total of 2000 Watts per person. By considering an average value of 60 m^2 per person, the resulting maximum limit value of primary energy is 122.2 KWh/m^2y [11].

This has been the theoretical target born in mind for the pilot building in Nebikon regarding both energy for heating, domestic water and electricity, grey energy and mobility-induced energy. The calculation method was notably based on the technical specifications developed by the Swiss Society of Engineers and Architects in reference document SIA 2040 (SIA, 2011).

Regarding energy for heating, domestic water and electricity, the building meets high standards concerning energy consumption as well as the Minergie-P label which is a very demanding Swiss energy standard.

The following main measures have been incorporated into the project : high performance thermal outer shell with better air-tightness, controlled air renewal, consideration of direction in the percentage of openings on the facades, removable exterior solar protection (with regulator), highly efficient technical installations (heat generation, electrical appliances), efficient lighting (fluorescent lighting or energy-efficient bulbs) attention paid to the lift and the standby of electrical installations, and use of renewable energy to meet all needs (heat pump linked up with groundwater table and photovoltaic panels on the roof).

At the energy sources level, supplementary effort has been made here regarding electricity. A contractual commitment has been agreed on with the electricity supplier in order to guarantee that additional electricity needs are met by exclusive use of electricity certified as being 100% hydraulic production (electric power with "naturemade star" seal of approval)

Parameters	Values
Wood structure	268 m^3 (European forest)
Wood façade	1425 m^2 (Swiss forest)
Number of wood elements	518
Windows	Triple glazing and wood-metal frames
Roof	Extensive vegetation
Ventilation (winter)	Controlled air renewal
Ventilation (summer)	Natural ventilation
Heat production	Heat Pump (groundwater table)
Construction to commence	September 2013
Electric production	157 m^2 PV Panels. Power with "naturemade star" seal of approval

Table 2. Constructive data for the pilot building

Regarding materials, the concept is based around the abundant use of wood, care taken in construction methods and a choice of materials that meets the requirements of the Minergie ECO label, which corresponds to a high standard of ecological construction in Switzerland.

As far as mobility is concerned, estimated calculations are based on reference values set out by reference document SIA 2040, bearing in mind the proximity of the railway station which encourages use of public transport (SIA, 2011).

Given the chosen building principles, the simulations and calculations show that the pilot building's global energy performance can meet the considered targets. Estimated values obtained regarding non-renewable primary energy are presented in Table 3, whereas those obtained for global warming potential (equivalent CO_2 emissions) can be seen in Table 4.

Phases	Non Renewable Primary Energy (NRE) KWh/m^{2}y	
	Theoretical targets	Pilot project values
Construction	30.56	36.11
Operating	55.56	1.11
Mobility	36.11	38.05
Total	122,23	75.27

Table 3. Estimated energy performances in Non-Renewable Primary Energy (NRE)

Phases	Global Warming Potential (GWP) Kg - CO2/m^{2}y	
	Theoretical targets	Pilot project values
Construction	8.5	9.0
Operating	2.5	0.4
Mobility	5.5	7.0
Total	16.5	16.4

Table 4. Estimated energy performances in Global Warming Potential (GWP)

Values obtained for the development of the pilot building highlight the indispensable role played here by using electricity which is 100% certified hydraulic power that greatly reduces non-renewable primary energy consumption and CO_2 emissions during the exploitation phase and thus compensates values of other components in the overall budget.

It appears, moreover, that global warming potential requirements are much harder to meet than non-renewable primary energy requirements (Pfeiffer, 2013).

3.3 Beginning the monitoring progress

To check on the building's actual energy performance and stimulate users' awareness in this area, a monitoring process has been installed in the building.

This pioneering system is available to each tenant who, thanks to a user-friendly browser, can control and manage their electricity, heating and water consumption. This helps to encourage responsible behavior regarding resource conservation.

The data gathering phase is still in progress. Depending on the outcome, it will not only be possible to check if these tally with the values expected, but also to envisage the optimization of operational processes where appropriate.

4. Conclusions

This interdisciplinary research project has allowed for the development of an innovative concept for wooden modular housing and its theoretical compatibility with the energy requirements inherent in the long-term vision of a 2000-Watt society. In this way, with simultaneous integration of environmental, socio-cultural and economic criteria, Swisswoodhouse is clearly part of a perspective on sustainable architecture.

Following the research phase, the realization of a pilot building has provided the opportunity to test the parameters developed within the development of the conceptual framework. This experimental approach has confirmed the need to consider a whole range of parameters, the increased difficulty of attaining requirements concerning CO_2 emissions and the crucial importance of using exclusively renewable energy sources for heating, domestic water and electricity.

Implementation of a monitoring process within this first building – experimental but with real residents – will also provide opportunities to build on other useful practical information over the months to come.

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