Copenhagen, 20-21 August 2015

7. Passivhus Norden | Sustainable Cities and Buildings

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Learning from Functionalist Nordic Houses towards Passive, Active, Adaptable and Prefabricated Homes

SUMMARY

This research presents a preliminary exploration to the definition of sustainable Nordic housing by appraising the qualities of four functionalist projects built prior to the energy crisis of the 1970s and four projects built after the year 2000, when sustainable design became an explicit target. The functionalist projects are: Erskine's Box, Aalto's Helsinki House, Jacobsen's, Gotfred Rodes vej House, and Korsmo's Planetveien House. The recent case studies selected are: AART Architects' Home for Life, Henning Larsen's Adaptable House, Rune's Tind Prefabricated House and Kaminsky Architecture's Villa Nyborg. The performance in terms of environmental sustainable design of the case studies selected are studued qualitatively and quantitatively considering climate, context, form, structure, materials, and architectural programme. Site visits, literature review, and computer simulation of daylight distribution, operational energy, and embodied energy are analyzed. The study revealed that traditional projects encompass a stimulating concept of comfort. In more recent projects, higher performance are the drivers of the design.

KEYWORDS

Sustainable Architecture, Single-family Houses, Functionalist Architecture

INTRODUCTION

Before the '60s, a series of modernist Nordic buildings – selected in this study – started to engage with the properties of building form, materials and thermal delight to "adapt" to the needs of their occupants and to the climate. Their design was based on an empirical understanding of physical processes and consideration of energy requirements, site and users. In the '60s and the '70s, energy was abundant and cheap; buildings around the world, including the Nordic countries, started to become reliant on energy-hungry mechanical systems, pursuing occupants' comfort via artificial lighting and air-conditioning within sealed building envelopes. However, the '60s and '70s also saw the humble beginning of a counter-view on the role of the environment and nature in architecture, with a series of experimental houses. Such designs were then labelled as 'low-energy', 'passive solar', 'energy-conscious' and, as the movement begun to grow, a substantial body of works evolved into new housing concepts. Over the following 30 years, also due to the energy crisis and the increased awareness towards issues of environmental sustainability, a gradual shift led from a rather narrow focus on mitigation strategies and minimisation of environmental impacts (all words that imply a certain sense of negativity) to a broader framework that includes concept such as: interactive, adaptable, and prefabricated houses. Given such a scenario, the aim of this research is to analyse the homes before the 60s' and after the 2000s. This research focuses on single-family houses. The sample study is composed of four modernist (1928, 1936, 1941, 1955) and four contemporary (2008, 2010, 2012) houses from Denmark, Sweden, Finland and Norway. The research investigates their performance of in terms of sustainable environmental design and how they contributed to the enrichment of places, people, ecology, and culture.

COMPARISON OF 8 HOUSES

The research seeks to identify how functionalist architects on the one hand, and a more recent generation of architects on the other, consciously or unconsciously have looked at climate, local resources, and human comfort. It also considers how environmental design concerns have been addressed through architectural solutions. The selection of the case studies has been determined on the criterion of whether their design had embedded, implicitly or explicitly, the aim of achieving targets in terms of sustainable environmental design. The selected buildings share their location in the Nordic geographical context, and they were all designed by prominent architects, with experimental aspects to their design. All the buildings are still in use, and they have all been widely-published.

Four of the buildings were designed before the '60s, and they were selected since they were all identified as "modernist" and are still in use. These are: Ralph Erskine's Box (Sweden); Aalto's

Helsinki House (Finland); Jacobsen's Gotfred Rodes vej House (Denmark); and Korsmo’s, Planetveien House (Norway). They have all been defined as “low–tech” buildings made of locally-sourced materials, their design is simple and affordable, and mostly use natural forces to provide an internal comfortable environment. Users interact with environmental controls (e.g., blinds, openings), thus supporting the development of a “relationship” between the occupants and the building, but also between the building and the external environment. Their designers aimed to visually integrating nature within the architecture.

The “new” case studies are: Home for Life Future Active House (Denmark); Adaptable House by Henning Larsen (Denmark); Tind Prefabricated House by Claesson Koivisto Rune (Sweden); Villa Nyborg by Kjellgren Kaminsky Architecture (Sweden). These case studies incorporate performance-based design concepts. The active house “thinks”, “learns” and “anticipates” users’ behaviour to minimize the use of energy resources. Tind House is the only unbuilt case study, but it was selected since it features the latest technological advances to reduce embodied energy and increase recyclability. Villa Nyborg was designed according to principles of biological shape, combining natural forces and sun position with occupants’ requirements. The Home for life is shaped around a typical Danish family life-path, and a series of partitions can facilitate the creation of new living models.

Figure 1. The 8 cases. Clockwise from upper left: Jacobsen's Gotfred Rodes vej House; Aalto's Helsinki House; Korsmo's Planetveien House; Erskine’s Box; Kaminsky Architecture’s Villa Nyborg; Rune’s Tind Prefabricated House; Henning Larsen’s Adaptable House; AART Architects’ Home for Life.

QUALITATIVE AND QUANTITIVE METHODS

Qualitative factors and the results of building performance simulations have been considered and compared in this study. Consideration of the ways in which buildings have responded to the requirements of their users, the site, the cultural and climatic context, and comfort requirements have been based on the analysis of drawings, published reviews, field visits to the buildings, and interviews with selected experts. The analysis has also included attention to user experience, as well as “ephemeral” and perceptual characteristics of the spaces. The modelling of building performance was conducted with the use of Revit (BIM) Building Information Modelling-based workflows (Fig.2). The models included the definition of the site and the properties of materials. A geometrical analysis was based on the 3D models. The resulting data included studies of compactness and WWR (window to wall ratio) by orientation. The BIM models were transferred to operational energy, embodied energy and to daylighting modelling tools as shown in Figure 2.

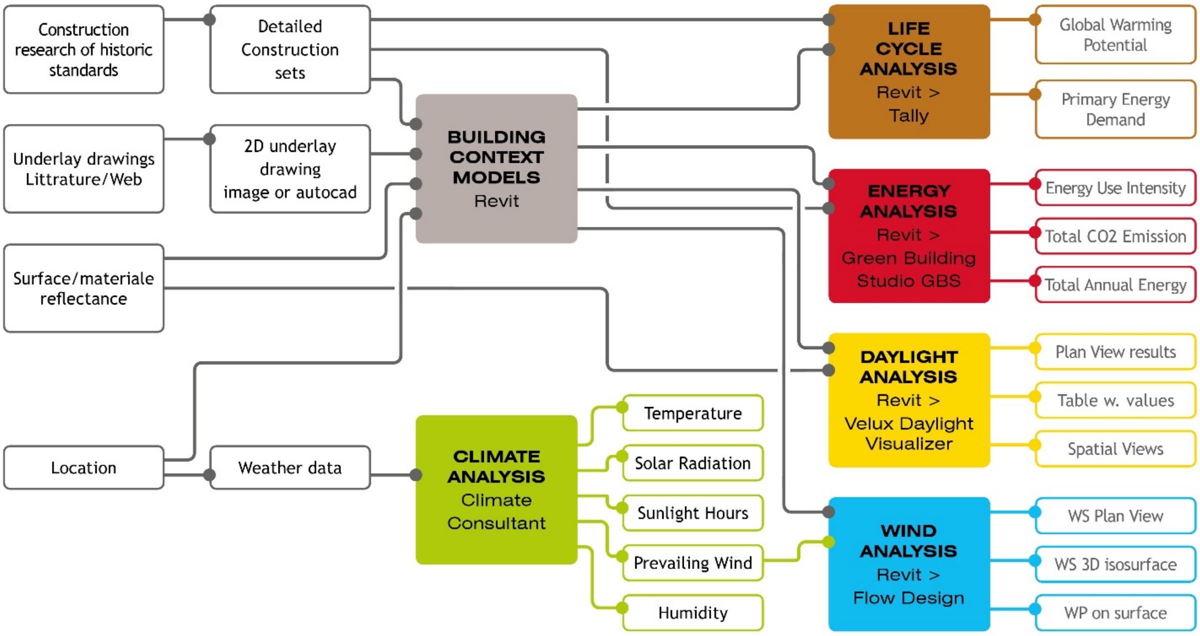

Figure 2: The workflow charts from construction research to building simulation (and related outputs)

COMPARING SIMULATION DATA AND ARCHITECTURE

Size, Form and Compactness

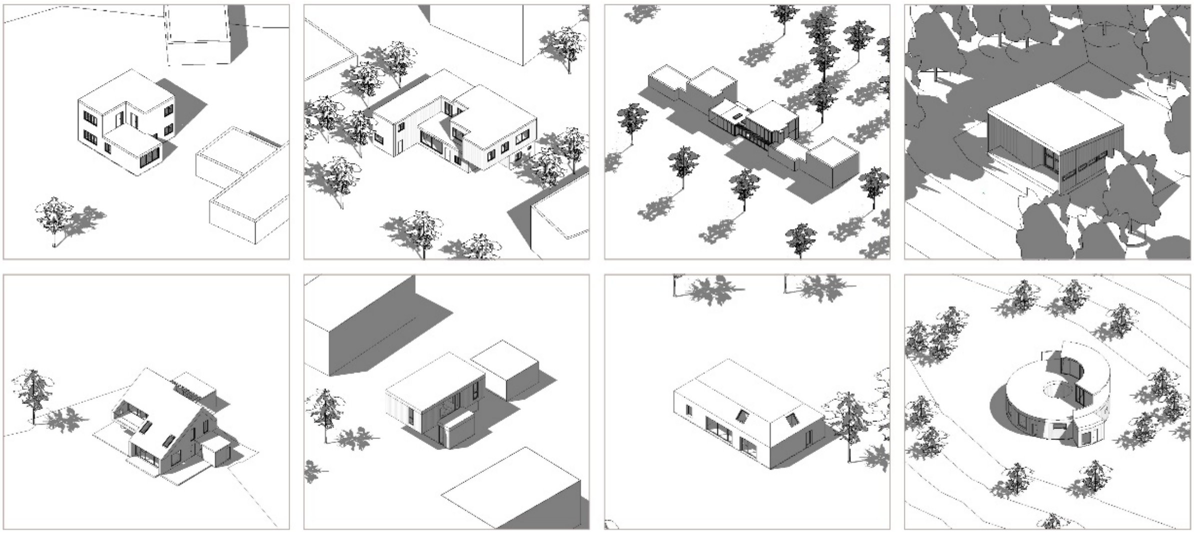

Figure 3. BIM models of the 8 case studies (clockwise from upper left): Jacobsen's Gotfred Rodes vej House; Aalto's Helsinki House; Korsmo's Planetveien House; Erskine's Box; Kaminsky Architecture's Villa Nyborg; Rune's Tind Prefabricated House; Henning Larsen's Adaptable House; AART Architects' Home for Life.

		Gotfred Rodes vej	Helsinki House	Planetveien House	Box	Home for Life	Adaptable House	Prefabricated House	Villa Nyberg
Floor area	sqm	151	321	151	25	161	129	145	182
Compactness	S/V	0.66	0.58	0.75	1.19	0.69	0.78	0.39	0.27

Table 1. Floor area and Compactness (expressed as Surface to Volume ratio; lower value = more compact). Data are extrapolated from BIM Models.

The eight buildings (Fig.3) present distinct and varied forms for interfacing with their microclimates (Table 1). With the exception of the Box, the old buildings are two storey-high structures with living and kitchen at the ground floor level and bedrooms on the first floor. All of the older case studies feature external patios and upstairs decks that benefit from direct solar gain (fig.4). The building form creates exterior “rooms” that are exposed to direct sunlight and are protected from prevailing winds; elevated terraces on the first floor allow for extended views, giving the users the opportunity to occupy external spaces. Seasonal occupancy of outdoor spaces adjacent to the buildings adds usable, “unconditioned” areas and the inhabitants gain high-quality space for living. This has an impact on the practicality of the compact buildings, and enhances user’s experience within the building and the outdoor environment.

Figure 4 Outdoor living space for seasonal use, Helsinki house terrace (photo: Anders Bengtsson)

The more recent projects enclose the occupied space within a tight thermal envelope. Home for life and Villa Nyborg (fig.5) are consciously oriented to optimize solar gain. The dominant form of the Home for Life is a roofline that slopes to the south for optimal integration of active solar technologies including thermal solar panels and solar collector cells. The form of the building also optimizes cross ventilation, drawing in fresh air at low level through windows and exhausting the hot air at high level through operable skylights. The Adaptable House has an upper level cantilever that shades the lower floor from direct solar gain in the summer and opens the interior to the external environment from more than one side of the living area. The internal walls are designed to move and adapt as occupants’ living requirements change. The Prefabricated House has a similarly dominant sloping profile that refers to the traditional Swedish roof and allows for “super-insulation” in the roof cavity. Villa Nyberg is an atypical round toroid-shaped building with a second storey on part of its floor plate. The round form optimizes exposure to the sunpath and the positioning of the windows maximizes passive solar heat gain. This building has the highest compactness factor. The separation between interior and exterior is a dominant formal consideration in all recent projects.

Figure 5 Villa Nyberg exterior; central courtyard brings light and heat into the building, and allows the building to be oriented to the northerly lake views (photo credit: Kjellgren Kaminsky Architecture)

External / Internal Heat Gains and Thermal Delight

Passive Design

In all cases, the WWR on the south and west are higher than on the north and east, and windows are mostly located on south facades (but in the Adaptable House) allowing for direct solar gain for heating (Table 2). For most of the case studies, the lowest window-to-wall ratios occur on the north facades. The traditional case studies are oriented with airlock entries on the “coldest” side of the building, while living spaces are located on the “warm” side, and bedrooms are upstairs. There are more individual rooms in these buildings, thus offering the opportunity to close off areas and thermally isolate them. Conversely, the more recent buildings have mixed-used living kitchen/dining areas, and – with the exception of Villa Nyberg – they eliminated the airlock entry system from their design. Views of a lake nearby Villa Nyberg drove the design and the orientation of windows.

		Gotfred Rodes vej	Helsinki House	Planetveien House	Box	Home for Life	Adaptable House	Prefabricated House	Villa Nyberg
Total	WWR	27%	19%	54%	15%	31%	26%	14%	8%
North	WWR	17%	13%	0%	0%	2%	17%	7%	9%
East	WWR	34%	16%	46%	16%	17%	21%	7%	2%
South	WWR	34%	31%	85%	44%	90%	29%	35%	9%
West	WWR	23%	15%	70%	0%	17%	38%	8%	14%

Table 2. Total Window to Wall Ratio of exterior Walls and based on orientation (%).

Solar Protection

The older case studies utilize internal insulating blinds and draperies to control heat gain/ heat loss through openings. These are manually operated and add to the texture, colour and beauty of the spaces. Although the older buildings do not have external operable window protection, they address the issues of summer shading with overhangs and light - diffusing structures. Conversely, in the case of the Home for Life, one of the design objectives was to integrate an “impressive array of technologies” with intelligent control systems whereas the building automatically adjusts the operation of windows, shades and lighting; these operations occur without the occupant’s direct control (Hansen).

Thermal Aesthetic

In the modernist “functionalist” buildings there is high integration between mechanical systems and architecture, a feature that could be defined as “Thermal Aesthetics”. The fireplace is a prominent architectural element in the older case studies (fig.6); these are focal points to the spaces in the buildings. These buildings have hydronic heaters (radiators) placed on peripheral walls underneath the windows (fig.7). In the Gotfred Rodes vej Home and Helsinki House, plant trays are positioned on the deep window wills, so that live plants contribute to the internal ambience of the house; nature is literally brought inside the spaces. In the cases with radiators under windows, the sill is deep so that the heat can be reflected back into the living space, improving upon efficiency and also creating a functional “shelf” on the window. The Planetveien building was originally designed with “warm floors”, a new technology at the time, although the architect regretted not putting radiant heating pipes in the stem wall underneath the windows (Tostrup).

The recent case studies use solar heating, active heat recovery and renewable energy systems combined with super-insulated, tight building envelopes that reduce energy consumption meeting code requirements. The heaters are visually hidden from the occupants in the new buildings, although this design choice undermines their cultural value and the opportunity to stimulate visual senses. These buildings were designed without a “visual” heating source in the spaces such as a fireplace or a radiator. So, despite impeccable technical functionality, these case studies may not get sull “acceptance” by their users due to culture-related user expectations. In the Home for Life, the iconic solar heaters are integrated into the façade of the home and collect energy for whole house heating and domestic hot water. No obvious heat sources are evident in the Prefabricated House, with the exception of the black fireplace.

The older case studies use passive ventilation, openable windows, ventilation shafts and tubes to facilitate air movement and exchange. Their wall sections are designed to “breathe”. This is different from the air tightness objective of some of the newer buildings. The latter use a combination of passive and efficient active ventilation systems, most notably employing mechanical heating recovery ventilators (HRV).

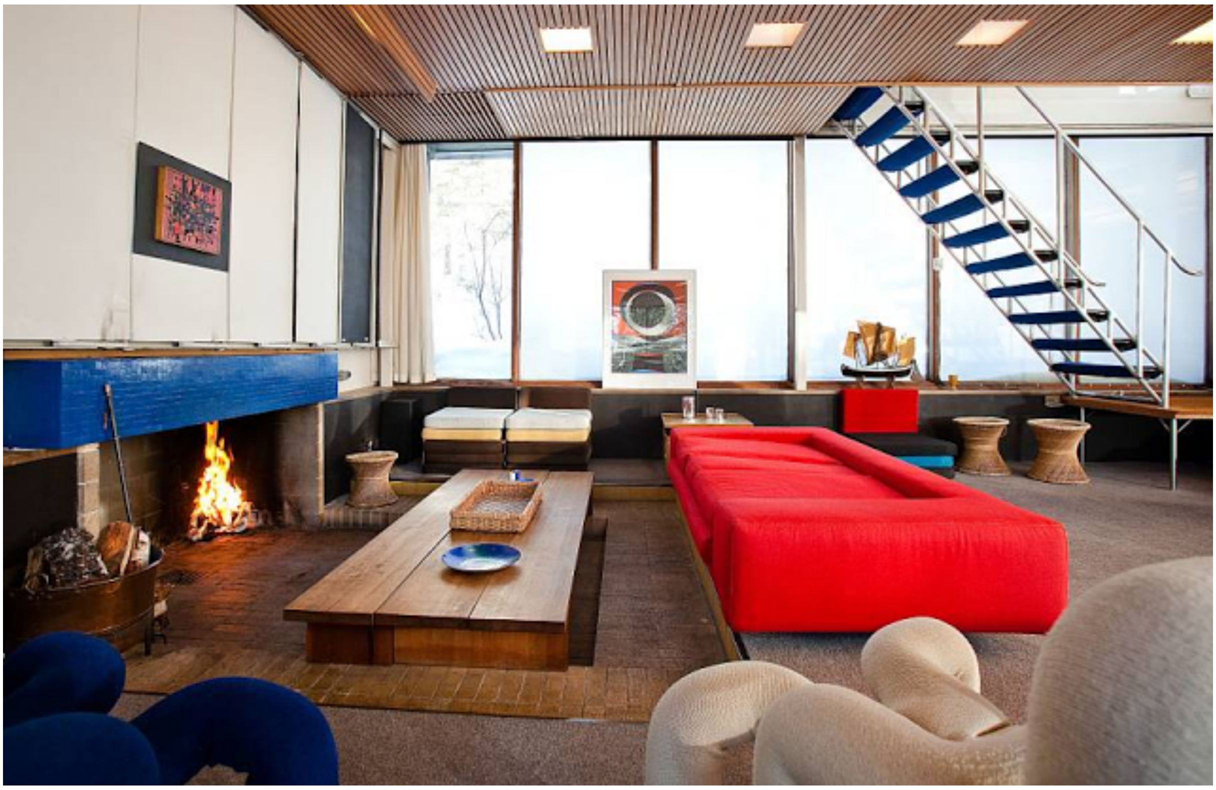

Figure 6 Fireplace functions well and is a prominent architectural element in the Planetveien home

Figure 7 Deep windows and planter boxes above heater with operable window in the Gotfred Rodes House (photo: Per Munkgård Thorsen/ Lars Degnbod)

Daylighting and Lighting

In the functionalist case studies, daylighting is an architectural material. The main living spaces have the largest windows, which are oriented to the south and west. In these houses, there is a special relationship between the location of the windows and skylights and the program. The Planetvein house is part of a triplex which could have been limited in terms of daylight availability, yet the architect utilized the building form to distribute natural light deep into the building. A stepping external garden on the west side allows daylight into the basement/studio. The building is designed to let in expansive natural light and play with transparency and translucency. The Box has easterly windows adjacent to the working/ living space at table height, so that, even if light levels are low due to dark internal materials and therefore low reflectance, the illumination of working surfaces is given particular attention. In the kitchen, light is reflected from the windows above to allow indirect lighting. The Helsinki house has a quality of lighting that is ideal for working conditions in the studio, whereas the living rooms downstairs and upstairs have south-facing windows that permit more direct, bright light levels. At the same time, skylights allow spaces in the centre of the building to access natural light directly.

All of the newer cases have brightly coloured interiors to reflect and bounce around natural light that is admitted through big windows and skylights. The building section of the Home for Life derives directly from angles of the sun, in the attempt to maximize solar heat. The control of the light levels in the newer cases may be evidenced by the differences between the illuminance values in summer and winter (Table 3). Such difference is reduced in the new buildings, hence indicating that these houses may have better control at limiting extreme daylighting conditions. In the older houses, the simulation for the summer months resulted in higher lux levels, possibly meaning that these buildings may not have a sufficiently fine-tuned shading strategy. However, analysis of winter lux levels does not lead to the identification of a univocal trend when comparing the older and newer cases. Villa Nyborg is carefully designed around view and daylighting concepts, and with a central atrium for a two-sided daylighting.

		Gotfred Rodes vej	Helsinki House	Planetveien House	Box	Home for Life	Adaptable House	Prefabricated House	Villa Nyberg
Position of the living space	South / East / West / North	South-West	North-East	West	South	South	South-Southwest	South	West
Summer	Lux	501	440	1114	681	316	798	413	415
Winter	Lux	172	45	180	54	59	149	102	286
Lighting – EUI	Kwh/m2/ year	70%	77%	80%	29%	88%	77%	100%	34%

Table 3. Simulated Illuminance levels for living spaces at 12 o'clock the 21 of June and 21 of December and Lighting Loads. Percent (%) factor of the maximum value.

Operational Energy Demand

The study is looking at how energy loads are reduced by efficiency of building design. The functionalist cases, with the exception of the Box, they have been renovated to improve energy efficiency and increase comfort. The Helsinki House was connected to district heating when it became available in the 1980s. The Planetveien home was connected to a geothermal heating system recently. Both projects therefore have improved the efficiency of the existing heating systems by connecting to more efficient technologies; thereby reducing their carbon footprint. The simulation data refer to original construction drawings. In order to compare the efficiency of design across the different cases, only the energy demand was calculated.

The simulation data indicates that the older cases demand significantly more energy to operate than the newer cases[1] (table 4). This is manly due to the focus of recent architecture on well-insulated envelopes. The box and the building form helps maximize the efficiency of the envelope: the north portion of the building is comprised of closets and wood storage which contribute to insulation. The south has expanses of glass. In the case of the Planetvein house,"the entire building got very hot." (Tostrup) because there were no operable windows upstairs; the building has been adapted with operable panes to improve upon this. There is ventilating space between the outer cladding that causes windbreaking. The Planetvein model shows it uses the most operational energy. The Helsinki

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[1] The data represents the cases as if they all have the same HVAC system and comparable lighting systems. This is not the reality. For instance, the box is designed with no electricity. The data is limited by the assumptions for the analysis. The data suggests usage patterns within a for contemporary context.

House has the largest volume that leads to very high-energy demand. The newer projects have lower operational energy (fig.8). They have tighter envelopes with lower U-value in the walls, roofs, floors and windows. For instance Villa Nyborg set a record for airtightness and insulation in Sweden, that combined with a very compact shape determines a very low energy need.

		Gotfred Rodes vej	Helsinki House	Planetvei en House	Box	'Home for Life'	Adaptabl e House	Prefabric ated House	Villa Nyberg
Heating	kWh/year	52%	100%	64%	3%	26%	10%	21%	7%
Cooling	kWh/year	45%	100%	81%	3%	48%	23%	40%	6%
Lighting	kWh/year	69%	100%	66%	3%	57%	40%	58%	25%
Total Energy Use	kWh/year	51%	100%	66%	3%	30%	13%	25%	8%

Table 4. Simulated Operational Energy Use Intensity. Percent (%) factor of the maximum value.

Figure 8 Adaptable house uses concrete in the base for thermal mass, and insulated frame for the upper cantilever (photo: Jesper Ray)

Materials and Embodied Energy Demand

The older cases experimented with new material technologies and building systems. Built in the functionalist era, the exterior wall sections for the Planetveien House, portions of the Helsinki home are thin, incorporating steel and glass in innovative ways. These new materials have high embodied energy contents. The windows are special double pane in the Korsmo house, which was built post-war when there was a “heavy rationing of materials and the state institute of housing recommended how to build; use as little material as possible.”(Tostrup). The Box is similarly experimental, with minimal materials due to the frugality required because of the World War II. It is constructed of a simple, renewable resource: wood. The Helsinki house includes large portions of wall composed of brick, concrete and layered wood. The exterior wall sections are designed to buffer the harsh winter winds with lapping wood that allows for a breathable façade. “It is a breathing structure; the wood based layers make no direct route for the air” (Pöyhiä). The wall insulation was originally sawdust; the roof insulation was originally cork; these materials have been updated with more modern materials and subsequent better thermal performance. In general, the new projects are achieving the goal of reducing carbon emissions and operational energy; as compared to the functionalist cases (Table 5). The prefabricated house is optimized to retain heat with highly insulated walls and roof assembly. The Adaptable house uses a thermal mass concrete block base with rockwool insulated frame construction above.

		Gotfred Rodes vej	Helsinki House	Planetveien House	Box	'Home for Life'	Adaptable House	Prefabricated House	Villa Nyberg
Primary Energy Demand (PED)	MJ over 50 years	16%	100%	57%	14%	27%	8%	15%	10%
Embodied CO2 Emission (GWP)	Kg of CO2 over 50 years	11%	100%	22%	6%	13%	4%	8%	5%

Table 5 Used materials Primary Energy Demand (PED) and Global Warming Potential (GWP). Percent (%) factor of the maximum value.

DISCUSSION

Building Performance and Human Factors

The functionalist houses pay particular design consideration to thermal comfort objectives as evidenced by their site planning, window placement, location of the primary heat sources, and building materials that are insulating or capacitative depending on their rlation to the program. Courtyards provide buffer zones. The north façades have the fewest windows. The buildings are designed to let in natural light and bright internal surfaces reflect daylight. However, if sustainability factors and architectural quality were solely related to performance data generated from simulation modelling, the newer case studies would prevail. The data tell us that they are more efficient, and use less embodied and operational energy than their traditional counterparts. Yet, quantification doesn't always address the quality of architectural spaces nor can properly consider the "human factor".

Climate-based Design Strategies

There are "implicit" sustainable ambitions embedded in the modernist buildings. The four case studies are at least 60 years old and their history of occupancy proves that they have proven to meet the criteria of durability. These projects incorporate climate-based design strategies that are appropriate for the climate and region. While both older and newer cases are designed to keep the heat in and cold out, and have low surface- to-volume ratios, modernist buildings seem to be more focused on seasonal programs. They utilize airlocks and buffer spaces along the north facades and minimize windows on all orientations except the south. In some instances, double glazing is used.

Thermal delight and thermal optimization

Modernist buildings place outdoor courtyards on the south side and let the winter sun in. They are all built on south, southeast, or southwest slopes. The presence of trees is minimized on the south side where spaces that benefit the most from direct solar heating are located. Conversely, storage spaces, staircases, and kitchens are located mostly on the northern sides. The buildings employ thermal mass to absorb and store solar radiation and use bright-coloured patios, pavements, or surfaces to reflect daylight. They have sunny but wind-protected outdoor spaces on the south side and utilize plants on the window sills for additional shading. These homes use shaded outdoor spaces, such as porches and terraces, and integrate vines on walls and/or trellises for shading. All of the buildings use natural ventilation for summer cooling. These strategies were employed before the formal definition of sustainable environmental design, yet they result in spaces of great quality.

The more recent cases studies have explicit ambitions to minimise energy use, employ passive and active environmental design principles, and test experimental technologies. These buildings also have deliberate objectives to offer flexible spaces and controlled luminous and thermal environments. The focus on efficiency, open floor plans, mechanically controlled climates, and automated systems may at times result in spaces that do not seem to pay deed to tactile or cultural links, or to consideration of occupancy where users are seen as continuously interfacing with the building and actively participating to the achievement of their comfort.

Vibrant Environments

The modernist buildings have been adapted, energy sources have been upgraded and improvements in insulation, ventilation, and roofing have been included. These houses have all been well maintained. Some of the original architectural qualities that contribute to their continued success are: vegetation integrated into the interiors and exteriors, varying lighting quality, thermal and aesthetic comfort. The occupants are engaged in the operation of the internal environment and the buildings are not as automated as the contemporary cases. These houses demonstrate an implicit understanding of the effect of climate on the spaces for living as demonstrated by the architectural form and relation to environmental factors. Human comfort is addressed within the quality of the spaces, from daylight penetration to access to solar radiation during the winter months.

CONCLUSIONS

The modernist houses could only access limited technologies, yet they show sophistication in their experimentation. When these buildings were built, requirements in terms of insulating materials, codes, standards, energy-conscious architectural design, etc. did not exist. Yet, they demonstrate value through their spatial and environmental qualities that still last to this very day. As Aalto wrote in 1940s: "*During the past decades, architecture has often been compared with science, and there have been efforts to make its methods more scientific, even efforts to make it a pure science. But architecture is not a science. It is still the same great synthetic process of combining thousands of definite human functions, and remains architecture. Its purpose is to still bring the material world into harmony with human life. To make architecture more human means better architecture and it means a functionalism much larger than the merely technical one. This goal can be accomplished by only architectural methods - by the creation and combination of different technical things in such a way that they will provide for the human being in the most harmonious life*" . (Schildt p. 103). There is a body of theory and practice accumulated during the modernist period (1930-1970) that can provide a substantial source of inspiration to contemporary design. However, that short period of time should be framed in the context of longer temporal boundaries. Many lessons for new design may be learned from the – what would later be known as – 'sustainable' buildings that pre-date the large use of energy performance systems in buildings. From such foundations, we may go forward with greater enthusiasm and creativity.

ACKNOWLEDGEMENT

Partial funding for this project was provided by generous support from the American Nordic Foundation; Alvar Aalto Foundation. The authors wish to acknowledge the feedback offered by Dr Sergio Altomonte, University of Nottingham, to the results of this study and the support provided in the preparation of the paper.

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