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Influence of multiphase flexible timber frame house construction on housing affordability

Roman Milwicz[a]* Piotr Nowotarski[a]

[a] *Institute of Structural Engineering at Poznań University of Technology, Piotrowo 5, 61-138 Poznan, Poland*

Abstract

Purchase of a large and expensive house becomes more distant vision for most people due to high initial cost, the size estimation difficulties, oversizing effects in higher mortgage and cost of maintenance. Recognizing those problems, a flexible multi-step construction of a house frame structure has been proposed, in order to reduce costs and adapt to the current needs of the end users. Proposed solutions are based on life cycle cost (LCC) analyses, monthly maintenance cost and flexible methodology. Paper presents comparative analysis of brick and timber structure frame house.

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Keywords: modular houses; timber frame structure; flexible design; sustainable design; life-cycle cost; house affordability;

Nomenclature

c_{in}	initial cost
c_{exp}	exploitation cost
$\sum c_r$	repair cost
v_r	residual value
c_{tech}	cost due to technical changes
c_{fun}	cost due to functional changes
c_{reg}	cost due to regulations

* Corresponding author. Tel.: +48-605-201-199
E-mail address: roman.milwicz@put.poznan.pl

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c_i	other costs

1. Introduction

Present times can be described by uncertainty either in case of future energy price or the case of heating. This situation takes place also in single-family housing sector. 40% of energy consumption is connected with building construction and maintenance [6] which forces scientist to undertake the case of reduction of energy consumption in the housing sector. Higher prices of energy and higher initial cost of building push clients to take bigger mortgage which decrease housing affordability (in case of preferable big houses). This causes gradual exclusion, especially for the poorest part of society –mostly young people, and leads to recession in the housing sector [1]. Solution can be provided by application in a various ways sustainability, energy efficient solutions and flexible design, which allows adjustment to current needs. Lowering energy requirements is connected, not only with reducing expenses on the maintenance of an object, but also and above all, with the comfort of determining the costs of its upkeep more precisely. Even in the case of significant changes in the prices of energy, the level of constant costs remains low. The case of fuel poverty was described in detail by Bolton and Department of Energy and Climate Change [2, 3]. The flexible approach during analysis of the problem on a global scale allows for a significant reduction of energy costs. The size of the object also has a great influence, as the need for usable area is not a constant value. The system of construction presented in this work provides good opportunities of flexibly adapting the usable area of the building to the needs of the end user, that is, it allows the building to be expanded or reduced thanks to modular solutions [4]. In order to analyze the problem the life cycle costs analysis has been performed and houses constructed in two different methods – traditional (brick) and modular (timber frame system), were compared. The comparative method -LCC (life cycle cost) provides a reliable look into the actual expenses connected with the building. Article shows also expenses distribution during the lifetime of the object, which is important aspect that indicates house affordability. As Gan and Robert say economic aspects such a housing costs and affordability may have important influence on sustainable development of the residential construction sector. [5]

2. Life-cycle cost analysis

The life cycle cost of a building is the sum of all expenses assumed throughout its existence, as well as when drawing up the blueprint for its construction, and during its disposal following the period of utilization. The aim of LCC analysis is choosing the most advantageous financial option from those available to the investor [3]. For last two decades rapid development in the field of life-cycle cost analysis can be observed. [7, 8, 9, 10, 11, 12] As far as the authors are aware, there were three significant analyses in the single-family housing sector. First in the USA in 2000 year [13], later in Finland [14] and in UK [15] in 2008 and 2014 respectively. In the paper similarly to the Peuportier [15] there is no discounting [16, 17]. The reasons for that are: firstly client in housing sector is focused on costs rather than financial- value terms; secondly the goal of the article is to show the general view on the problem of housing expenses. Moreover most expenses go parallel so the discounting will not cause big differences. Additionally family is generally interested not in whole life cycle of a house but in some part of it, the case was mentioned by Arja, Sauce, Souyri [18] and presented in the Fig.1a. From the typical LCC cost for single family house presented in the Fig.1b. it is easy to see that both initial costs and maintenance pays importance for final user.

There is also a mathematical formula of life-cycle cost is presented below. According to formulas 1 and 2 LCC consists of initial cost, exploitation cost, repair cost and residual value.

$$LCC = c_{in} + c_{exp} + \sum c_r \pm v_r \qquad (1)$$

$$\sum c_r = c_{tech} + c_{fun} + c_{reg} + c_i \qquad (2)$$

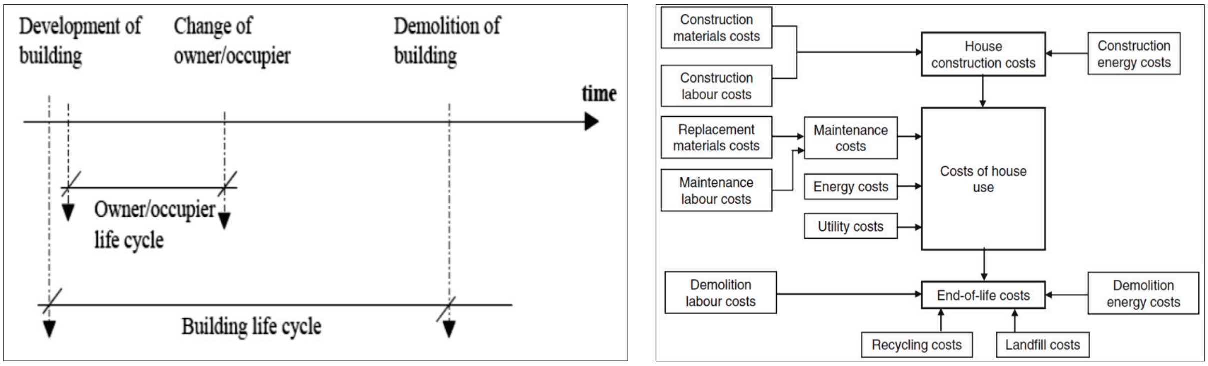

Fig. 1. (a) Fraction of life cycle of a structure concerning the interest of the user. [19]; (b) The life cycle cost of a single family house. [20]

3. Flexibility approach

Many definition of flexibility can be found in the literature. Flexibility has roots in manufacturing systems [22, 23]. There are many papers concerning management systems [24, 25] in the construction field where flexibility is broadly described by de Neufville [21] and Kulatilaka [26]. Upton describe the flexibility as “the ability to change or react with little penalty in time, effort, cost, or performance” [27] Lim considers flexibility as ability to adaptation or respond possible to reverse as a function of time and function in changing environment [28] on the other hand Wadhwa and Rao [29], emphasize the ability of implementation number of scenarios which simplify the setup of good decision. Cardina, Steer, Nuttall, Parks, Goncalves, de Neufville [30] state that “flexibility reduces the effect from downside, risky scenarios, while positioning the system to capitalize on upside, favorable opportunities. “

3.1. Forecast

Future is unpredictable, forecasts are “always wrong” as de Neufville, Scholtes [21] say: in dynamic changes of market conditions it difficult forecast future on historical data. The fact is that it is easier to predict close future than to prepare accurate long-term forecast. Probability of mistake rises with the time and one do not know which direction can fallow the changes, thus there is the need to design for future changes.

3.2. Flexibility in construction

Early design phase has huge influence over construction running costs. Optimization is simple and has wide range with a little cost. [8] According to Bogenstatter early design stages determine up to 80% of building operational cost and environmental impact. [31] Figure 2a. presents cost distribution in time and potential changes and savings. Early phases allow implementation of flexible technical solutions helpful in future.

There are many differences between conventional and flexible design. Flexibility is characterized by change of attitude towards risk, searching opportunities and avoiding risk. This is done by proactive behavior- preparation to possible events (positive and negative) accelerating response [33]. Table 1 is a comparison between flexible and conventional approach.

In this article flexible design advantages will be also presented. Dramatic reduction of costs connected with the special design for change will be achieved by changing the useful floor area in time. This will lead not only to energy consumption reduction but also to decrease mortgage costs. Adaptation to the actual need of customer will increase the usage comfort for end users.

Table 1. Comparison between conventional and flexible approach to infrastructure design [33]

No.	Conventional design	Flexible approach design
1	Risk- as only one side of the distribution (negative)	Risk and opportunity
2	Reactive	Proactive
3	Design to specification	Design for change
4	In technical space	Technology and economy management

4. House affordability

Housing affordability is an important factor and has great influence on the market condition. Recently declining housing affordability can be observed, which concerns mainly young people. There is lack of small and low cost houses available on the market and excess of big houses thanks to dynamic change in family structure. Small 2+1 or 2+0 families replace 2+3 families. Deregulations of the mortgage market helped many households to purchase a house or flat, but unfortunately it led also to rise in a house price. Easier access to mortgage increased payment time- this led to higher final cost of house and longer burden of household. The situation will lower of potential help for future generations. Housing affordability according to the authors can be described in three ways:

- Purchase affordability
- Repayment affordability
- Income affordability

Purchase affordability indicates household's mortgage capability in order to purchase house. Repayment affordability concerns effort of mortgage repayment and income affordability shows the ratio of housing costs and income. [5] By understanding housing affordability in this way authors analysed the conception of flexible housing enabling to purchase a house with lower effort. Figure 2b. presents the average monthly salary in polish zloty (PLN).

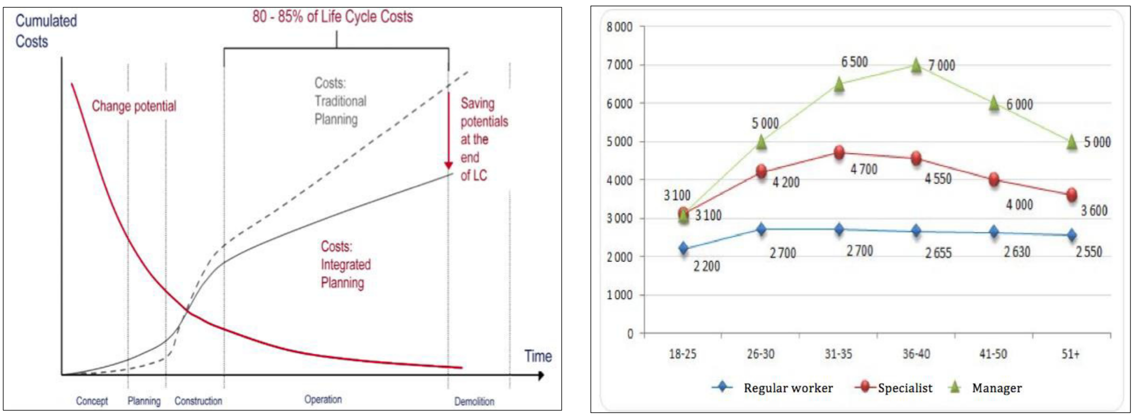

Fig. 2.(a) Cost development vs. change potential over building life cycle. [32] (b) Salary structure in Poland [34]

The shape of the scheme resembles the normal distribution and is very important in analysis of household affordability in time for the polish market. Housing expenses should be as much similar as possible to the chart shape. An interesting fact mentioned below in analysis is that demand for the useful floor area has congruent shape- and it was used in comparison.

5. Modular housing

Modular prefabricated construction can be a solution characterized by a multitude of adaptive qualities. Above all, the reduction of costs through prefabrication, which makes this type of construction independent of weather conditions, must be mentioned. By conducting the construction work at one location, the costs of delegating workers are reduced, shifts can be extended thanks to a constant temperature and lighting of the production hall, as well as the proximity of the industrial unit to the workers' place of residence (short time of commuting to work), and the fact that modularity is characterized by a better use of materials translates to the possibility of reducing waste. The set location makes it easier to choose building material suppliers and negotiate additional discounts, which further lowers the costs of production, thus increasing competition on the construction market. The effect of such actions is building time decreased by 30-50%. With this type of construction, investor deals with specialized workers who increase the quality of the final product. This has utmost importance over the course of use and limits the formation of sources of erosion. Modular buildings are characterized by a lightness of construction, which makes it possible to relocate the segments easily, and at the same time makes it unnecessary to construct large foundations, which are costly and time-consuming. When faced with the constantly increasing costs of building property, building plots are characterized by smaller surface areas, and thus the supply of land available for construction decreases. Prefabrication makes it possible to run a building project with almost completely eliminating the need for additional storage area on the building site since the prefabricated construction is delivered and assembled on location using cranes, without the need to store building materials [35].

5.1. Concept module

Over time the need for more useful floor area is changing. The main reasons behind this include:

- Offspring.
- Career development - office space.
- An additional car (garage).
- Taking up hobbies - hobby room.
- Elderly family members requiring care taking up residence.

It should not be forget that some situations are not of a permanent nature, and families can resign from the additional space once they cease to apply, thus lowering the costs of maintaining the whole building. An example of this happens when children become independent and leave the family household. A similar situation occurs in the case of the elderly; upon retiring, house owners do not need a house with multiple rooms, and those located upstairs often become too difficult to access. The reduction to a single-store home will therefore be a great convenience. The redundant segment can be adapted to serve as a recreational object or be used by other families. The form of the building structure depends greatly on the size of the building plot on which it is situated. Due to its high carrying capacity and simple form, (rectangular shape) makes it possible for the completed object to take various forms.

6. Comparative analysis

Comparative analysis concerns comparing two technological solutions - traditional construction (brick) and modular construction (timber frame) built in phases. The surface area of the object in traditional technology will not undergo change, whereas the modular system will facilitate such modifications (Table 2). The object is intended for a family with two children, who were born five years and ten years after marriage. What is more, the family sets up a business, which after twelve years of marriage requires an additional room - a home office. The dependency of surface area on time has been presented below. According to Polish central statistical office the average useful floor area of private house in 2014 in private sector is equal 148.6m2[36] for simplicity of calculation useful floor area is set 150m2.

Table 2: Changes in total surface area of the home over time

Time after setting up the family	Traditional construction [m2]	Modular construction [m2]	Reason in changes of useful floor area
0-4	150	40	Establishing a family
5-11	150	80	Child requires own room
12-28	150	150	Second child requires own room, office
29-42	150	80	Children start to move out
43-50	150	40	Retirement

The useful floor area of a building in traditional technology is the same as in the case of modular buildings at its peak. It ought to be noted that building such an object at once involves large outlays, which are almost always connected with taking out a mortgage by the investor. Long-term loans generate additional costs connected with paying them off. Another significant aspect is ensuring an adequate amount of energy, dependent mainly on usable floor space. Competently choosing surface area to match a family's current needs leads to the rationalization of costs of heating the housing unit. Decreased energy consumption limits the detrimental influence on the environment, and from the economic perspective, lowers the costs of house maintenance. The psychological aspect, or psychological comfort to be more precise, connected with small fluctuations in costs of heating the house should not go unnoticed; a small amount of energy will not alter expenditures significantly even when prices increase dramatically. The same cannot be said of costs connected with high energy dependence.

6.1. Cost analysis

Due to the high uncertainty connected with the prices of energy, two external variants of its changes over time have been presented. For simplicity linear growth of energy has been set. Option A represents the appreciable increase in energy prices whilst option B represents moderate option. Due to uncertainty real costs should be found in the interval of given options. It is assumed that house hold posses a plot and saving of 100 000 PLN for investment. The table below presents set conditions.

Table 3: Data for building life cycle cost analysis

An example of a column heading	Traditional construction		Flexible construction
Cost of building "turn-key" home	3,000 PLN/m2		3,500 PLN/m2
Cost of mortgage		4% mortgage,	
Energy requirement	120 kWh/m2 year		40 kWh/m2 year
Maintenance costs		20 PLN/m2 year	
Initial capital		100 000 PLN	
Energy price[PLN/kWh]		A 0.25-1.75	
(changes linearly in 50 years)		B 0.25-0.5	

Simple life-cycle cost presents notable difference between two options in both cases- A and B- (Fig.3b). Worth indication is also the slope of the curve. More delicate slope can be observed at the beginning and the ending in modular construction, which indicates smaller economical burden for a household in those periods, and according to figure 2b the capability of household is much lower in this time. The most steep slope part presents mortgage repayment which is also reduced in flexible approach.

Reduction of energy demand by application high quality materials and mechanical ventilation with heat recovery decrease significantly energy demand. Moreover, changing useful floor area in time additionally reduced energy costs. Reduced useful floor area in extremes of time scope not only decreases comfort but also is welcome state. Cost reduction is especially visible at the ending time of analysis and can reach drop of 90% value of inflexible solution. Energy costs are presented on figure 4a.

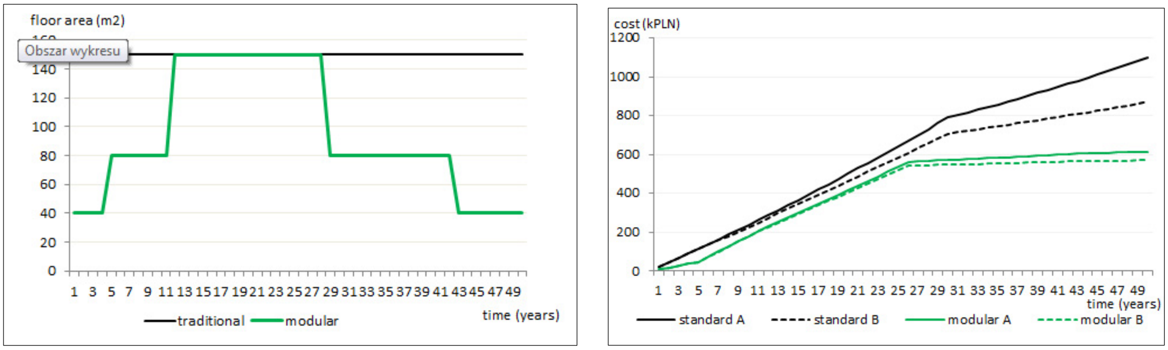

Fig. 3 (a) Change in total usable floor space over time. (b) Life cycle cost of building.

When taking into account investigating case mortgage situation costs of energy and mortgage repayment are presented on figure 4b. Main costs at the first 26-30 years are generated by mortgage repayment. For a short period cost of flexible solution are higher than for regular construction but taking into account figure 2b. it occurs in the top affordability of household. The shape of flexible solution is more congruent to affordability presented previously.

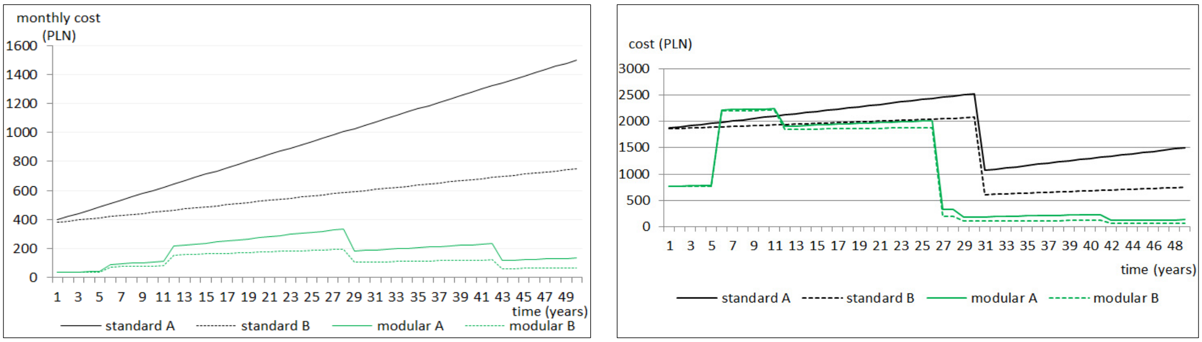

Fig. 4 (a) Monthly cost of energy consumption in building (b) Monthly energy and mortgage cost in building.

7. Conclusions

Flexible design and construction can have significant influence on maintenance of a building and can lead to dramatic reduction of costs at the level of even 50%. Additionally it allows for the rational distribution of costs over time, which in turn eliminates the need to take out long-term mortgages, which also raise the costs of an investment.

This type of construction facilitates adapt better to both current and unexpected needs by increasing or decreasing the useful floor area of the building. An important aspect is also the option of decreasing home size when the investor retires which, in addition to financial benefits, reduces house maintenance costs. Construction in phases can be conducted in any system, whereas timber construction is characterized by lightness and the simplicity of making changes to the object - qualities which are not met as effectively by traditional technology.

Differences in building life cycle costs are clear and undoubtedly in favor of modular frame construction. The structural features of the object allows for the flexible adaptation to unexpected situations, such as a new member of the family or setting up a business.

What is more, construction is not complicated, fast, and does not impinge much on the life of the inhabitants during its realization. Flexible house is more affordable, additionally is the way of sustainable development in single-family housing. Disadvantage of modular house is need of high quality of a structure, which can be difficult to obtain in some cases.

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