Comparing the Economic Indicators of Sustainable Development in Wooden Housing

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Abstract. Sustainable development as a concept of construction arose some 20 years ago. Nowadays, this is a global trend in conventional construction. This paper analyzes the sustainable development indicators, mainly the economy of wooden housing. The proposed method for calculating the economic sustainability indicators is based on calculating the full life cycle of a house with a breakdown into such stages as design, construction, operation, and disposal. The paper compares wooden housing against conventional reinforced-concrete residential buildings in terms of this economic indicator. Stakeholder analysis assesses the sustainability factors (environmental, economic, and social); the assessment can be used to draw sustainable development policies, strategic goals and objectives pertaining to wooden housing.

1. Introduction

Wooden houses meet many requirements of ‘green construction’, as wood has unique ecological properties, provides outstanding heat insulation, is easy to machine, and is suitable for any climate; this is why industrial-scale wooden housing is one of the fastest-developing parts of the construction industry.

This is why researchers are interested in the analysis of the sustainable development indicators of wooden houses. This paper seeks to calculate the economic sustainability indicators of buildings on wooden frames, to find out how the distinctive features of wooden housing affect their financial performance over the life cycle, and to identify the key factors in the structure of the economic sustainability indicator applicable to wooden housing. To that end, it compares wooden housing against reinforced-concrete buildings in terms of this economic indicator, and assesses the sustainability of wooden housing by means of stakeholder analysis. The research output may be used to draw sustainable development policies, strategic goals and objectives of wooden housing construction in the context of its specifics.

One of the basic sustainability indicators applicable in construction is the so-called life-cycle cost, or LCC. This idea is to minimize the costs accrued over the life cycle for a more competitive pricing [1-3]. LCC must cover all the life-cycle phases of a building [4]. The cost of a building is a total of all real costs incurred during construction, operation, repairs, and demolition [5,6].
Calculating the effective economic indicator uses a scenario that is not limited to the life-cycle costs expressed in monetary terms; rather, it also takes into account revenue generated from the house. It is often believed that the revenue category provides an assessment of the comparative financial performance of a building and helps identify the financial benefits it provides. The category includes any of the owner’s revenue generated from the reuse, disposal, and recovery of energy resulting from using the material and component flows as resources for potential reuse [6].

2. Methods

The assessment presented herein builds upon a standard approach [7,8], which enables assessing the efficiency of each stage and considering the calculated values as early as possible when designing a building.

To capture and compare the current and future construction costs, LCC analysis usually uses the net present value (NPV) [9-11]. NPV is a subtle economic method that is based on analyzing the temporary value of money [5]. This method takes into account all the cost flows of a building and discounts them to the current value by applying a preset rate [12-13]. When it comes to choosing from mutually exclusive solutions, the one that generates the greatest NPV is the most cost-effective and investment-worthy option [12, 14].

However, as noted by Shade [14], LCC focuses on costs rather than revenues, i.e. life-cycle costs are deemed positive while revenues are deemed negative. Thus, the most cost-effective option of two competing alternatives is the one that has minimum NPV [5,9,16]:

\[
NPV = \sum_{t=0}^{n} \frac{C_t}{(1+d)^t} - IC
\]

where \(NPV\) is the net present value of all cash flows;
\(C_t\) is the net cash flow over year \(t\);
\(n\) is the life cycle in years;
\(d\) is the discount rate to adjust cash flows to the current value;
\(IC\) is the total initial investment.

Let us calculate the indicators using data from the Bridport House in London. This was one of the first modern multi-storey buildings that used a complete CLT structure, including the ground floor. Besides, the building is good for assessing the life-cycle costs as it has an appropriate operation period.

Its design is a good combination of massive wood and other construction materials such as bricks, aluminum, and copper that are used in the facade architecture. CLT slabs have a total volume of 1,576 cubic meters; those are prefabricated slabs made in Austria. Timely delivery helped considerably shorten the construction works and spend less human hours on the site [17,18].

Table 1 presents the LCC for the Bridport House over a 30-year research period. For the design stage, the analysis takes into account the following costs: cost of construction materials and products; cost of delivery from the supplier to the construction site; cost of professional services, including design, cost analysis, planning, and developing the design specifications; cost of construction works and connecting to the public utilities; cost of land development, taxes, and other costs pertaining to various permits that were necessary to commission the building. For the operation stage, the analysis takes into account: insurance costs, taxes, cost of repairs and replacing smaller structural elements on a smaller scale, cost of overhauling the fundamental systems and elements, cost of maintenance, cost of resources. For the demolition/disposal stage, the analysis takes into account dismantling costs and related transportation costs; costs generated by re-use of energy at the completion of the life cycle, revenue from selling the land.
The costs and revenues generated at each stage are shown in the bottomline (‘Total’) and correspond to the total cash flows without applying any interest rate. Present value corresponds to the cash flows generated over the life cycle and discounted to the current value. Thus, presenting the cash flows in terms of total and current costs highlights the differences between the figures, which showcases the important of cost timings and accounting for investments necessary to create value. Besides, the Table shows which category of costs and revenues features the greatest difference across the life-cycle stages. Finally, the Table presents the NPV of costs for a wooden building. To further assess the economic potential of a wooden building, LCCA compares it against the cost components of a similar reinforced-concrete residential building. The comparison seeks to evaluate the LCC difference between two buildings that offer identical physical conditions but use different materials. Thus, a reinforced-concrete building is structurally similar to a CLT building except that it uses reinforced-concrete slabs instead of wooden bearing walls. The quality of other interior elements, be it stairs, partitions, flooring, doors and windows, fittings and trimming, is identical to that of a wooden building.

| Costs                        | Total, £       | Present value, £ |
|------------------------------|----------------|-----------------|
| Before Use                   |                |                 |
| Design and fees              | 221,600        | 221,600         |
| Overhead and Profit          | 368,700        | 368,700         |
| Preliminaries                | 637,800        | 637,800         |
| Building                     | 4,708,900      | 4,708,900       |
| Interest charges             | 195,500        | 195,500         |
| Total                        | 6,132,500      | 6,132,500       |
| Operation                    |                |                 |
| Maintenance costs            | 2,340,000      | 1,512,600       |
| Energy use costs             | 823,550        | 546,800         |
| Replacement costs            | 2,507,000      | 1,185,100       |
| Total                        | 5,670,550      | 3,244,500       |
| After Use                    |                |                 |
| Demolition and waste         | 1,417,700      | 599,900         |
| management costs             |                |                 |
| LCC                          | 13,220,700     | 9,976,900       |
| Revenue                      |                |                 |
| Materials recycling revenue  | 65,900         | 27,900          |
| Materials reuse revenue      | 303,800        | 128,500         |
| Energy recovery revenue      | 32,600         | 13,800          |
| Rental income                | 42,101,700     | 28,159,200      |
| Total                        | 42,504,000     | 28,159,400      |
| NPV                          | -29,283,300    | -18,352,500     |

Table 1. LCC for a wooden house over a 30-year research period.

LCC helps compare both. Table 2 compares the current value for each life-cycle phase and its variation. It also identifies the difference between the net current value of wooden and concrete buildings. The most cost-effective alternative is the one that has a lower NPV of costs.
Table 2. CLT vs RC: NPV comparison over a 30-year research period.

| Cost/Income       | CLT, Present value (£) | RC, Present value (£) | Variation (£) | %  |
|-------------------|------------------------|-----------------------|---------------|----|
| Before USE costs  | 5,937,000              | 5,692,800             | 244,200       | 4% |
| Interest charges  | 195,500                | 233,200               | -37,700       | -19%|
| USE costs         | 3,244,500              | 3,413,600             | -169,100      | -5% |
| After USE costs   | 599,900                | 343,300               | 256,600       | 43% |
| LCC               | 9,976,900              | 9,682,900             | 293,900       | 3%  |
| Income            | 28,159,400             | 28,080,400            | 249,000       | 1%  |
| NPV of costs      | -18,352,400            | -18,397,500           | -45,100       | 0.2%|

3. Discussion of results

Thus, LCCA performed for a 30-year lifecycle of a wooden building estimates the current Before Use costs at 5,937,000 £ or 59% of its total costs, whereas the Use costs account for 33%, with the remaining 6% being the present value of After Use costs, see Table 2, Figure 1.

![LCC breakdown for a CLT building over 30 years.](image)

Similar calculations have been run for a similarly sized reinforced-concrete building completed in the same year and located in Helsinki. Let us further compare the LCC of a wooden building and its reinforced-concrete counterpart shown in Figure 1. The comparison shows that while the costs breakdown is similar, a wooden house carries higher construction and demolition costs [18]. CLT construction costs are slightly (4%) higher. Of importance is the time gain (CLT construction is faster than its more conventional RC counterpart); the key factor is the added value generated by fire safety and longevity improvements as well as enhancing the resistance to rotting and pests, which stakeholders believe is only a temporary obstacle that is due to underdeveloped technology and lack of specialists coupled with the popular distrust of the existing wooden construction technology.
However, calculating the NVP shows a wooden building has only 0.2% NPV than its RC counterpart. Thanks to prefabricated modules and less capital construction works [19-21], CLT construction took only 13 months, cf. 15-month RC erection works. The two-month difference resulted in a sooner commissioning, which means the building began generating revenue earlier. Besides, faster construction meant faster repayment of the credit line. This reduced the CLT-incurred interest charges by 19% compared to RC.

Operating costs did not differ significantly: -5% in favor of CLT. The RC building was a hypothetically constructed building, the operating/maintenance costs of which are based on averaged energy prices. For CLT, the operating costs were 5% lower. Note that the after-use costs of the CLT building were 43% higher than those of the RC building. This was due to the CLT building requiring a centralized fire protection system [22-23]. Disposing of a CLT building is 43% more expensive than disposing of an RC building. This is due to the high re-usability of CLT elements as recyclable materials in new production [24] coupled with the rather costly and time-consuming technology for dismantling wooden houses.

Thus, calculating and comparing the economic sustainability indicators for wooden and reinforced-concrete houses, namely the NPV, on the basis of LCC analysis shows that even today, wooden housing is sustainable and not inferior to conventional construction.

Stakeholder analysis to be presented further involved more than 30 specialists in wooden housing construction and applied SWOT analysis to identify the pros and cons of wooden structures that affect its sustainable development. The pros and cons are summarized in a matrix (Table 3) that assesses how pros and cons may affect the key factors of the three sustainability indicators per the standards [7,8]. Assessment uses a scoring scale with a maximum value of 5; the higher the score, the greater effect this advantage has on sustainability.

The matrix shows that exploiting such pros as the unique technological and esthetic traits of wood, the ease and simplicity of construction helps fully meet the sustainability requirements, especially those of social sustainability for consumers. However, the innovative wooden housebuilding technologies and consumers’ low awareness of its advantages limit sustainability. Stakeholders believe the economic sustainability is mainly affected by such factors as the dropping prices of making wooden structures, products, and materials, as well as the ever lower prices of professional services, from design to disposal; whereas the prefabrication market is advanced, the wooden construction market lags behind.
Table 3. Analysis of sustainability-affecting factors in the light of pros and cons.

| Pros and cons | Main factors of wooden housebuilding sustainability on an industrial scale |
|---------------|----------------------------------------------------------------------------|
|               | environmental sustainability | economic sustainability | social sustainability |
| Pros          | use of eco-friendly materials | faster construction | from design to disposal |
| 1             | 5                           | 4                     | 4                      |
| 2             | 5                           | 5                     | 5                      | 5                      | 4                     | 48                     |
| 3             | 5                           | 5                     | 3                      | 2                      | 5                     | 5                      | 5                      | 5                      | 5                      | 5                      | 40                     |
| 4             | 5                           | 5                     | 5                      | 5                      | 5                     | 4                      | 5                      | 5                      | 5                      | 5                      | 5                      | 5                      | 5                      | 5                      | 5                      | 5                      | 5                      | 5                      | 54                     |
| Cons          | regulatory framework is inadequate | compliance with building codes | compliance with quality standards | Total score |
| 1             | -5                          | -3                    | -1                     | -4                     | -3                    | -4                     | -4                     | -3                    | -5                    | -4                     |
|   | High-tech wooden housebuilding |          |
|---|-------------------------------|----------|
| 2 |                               | -53      |
|   | advanced                      | -5 -5 -5|
|   | Wood                          | -5 -5 -5|
|   | in terms of fire safety,      | -5 -4 -4|
|   | rotting, soundproofing,       | -43      |
|   | durability, and cracking      |          |
|   | Popular awareness             |          |
|   | of the benefits of            |          |
|   | wooden housing                | -53      |
|   | leaves much to be desired     | -3 -3 -3|

**Notes for Table 3:**
1. Scale of impact of pros on the sustainability factors:
   - 5, decisive impact;
   - 4, strong impact;
   - 3, moderate impact;
   - 2, weak impact;
   - 1, little to no impact;
2. Scale of impact of cons on the sustainability factors:
   - 5, fully disabling;
   - 4, disabling to a great extent;
   - 3, moderately disabling;
   - 2, disabling to a low extent;
   - 1, barely disabling.
4. Conclusions
Furtherance of sustainable development principles in construction opens up ample opportunities to use wood in residential highrises. Economically, it is very important to manage the costs of, and income from, operating a wooden building over its entire life cycle to improve the sustainability and return on investment. This paper uses NPV to assess sustainability. Analysis has produced the following findings:

(1) Even today, wooden houses are economically on part with their more conventional RC counterparts;

(2) Technological advancement is the key to lower wooden housebuilding costs. This is primarily due to the legal restrictions present in many countries that limit the use of wooden structures in housebuilding; another reason is that professionals are rarely interested in wooden housing. As such, the industry lacks competent specialists and professional unions.

(3) Stakeholder analysis presented herein is not merely a sustainability assessment; rather, it can be used to set forth strategic development targets that will address the weaknesses of this sub-industry while amplifying its cons and improving stakeholders’ satisfaction.

However, since wooden residential highrises are rare, this research uses only limited data; it can make use of a more detailed assessment with breakdown by materials and structures in use. Further research will create variation in the characteristics of construction materials and technologies; it will also employ better-adapted assessment methods using larger data samples with all the three sustainability indicators brought into light.

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