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Why invest in a reversible building design?

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Abstract. Commercial buildings often have a much shorter service life compared to their technical life. Change in market needs is a leading reason for their premature demolition. "Reversible buildings", which are capable of transformations in function and structure, are of high relevance for this building category. Reversibility starts with design. How can the investors be convinced to invest in a building with reversible design in the first place? The market value of commercial buildings is determined by the revenue they can generate through their service life. If the flexibility enabled by reversible buildings can be translated into higher market value, that could provide short-term incentives to invest in a reversible design. In this study, a quantitative financial model has been developed based on a real-life commercial office building in Flanders. The Net Present Value (NPV) of the building is calculated for both reversible design and conventional design. It was concluded that reversible design can deliver a more positive NPV compared to conventional designs, already with today's available technologies and market conditions. The key value driver of reversible design is investment risk reduction. In particular, it reduces the risk of low return-on-investment or even loss due to early demolition. Stakeholder engagement (such as real estate investors and appraisal professionals) will be essential to validate such added value. Sensitivity analysis recommends future research and development of reversible buildings in reducing initial investment (design and build costs) and increasing use phase benefits.

Keywords: business case, financial model, reversible design, commercial building

1. Background and research question

Reversible building design, which facilitates transformation in building function and structure, is envisioned to deliver environmental benefits by reducing demolition wastes and new material inputs. Commercial buildings on average have much shorter service life compared to their technical life. Leading reasons for commercial building demolition are often economic, such as area re-development and change in legislation or market needs (e.g. population growth) [1]. Therefore reversible designs, like those developed in the H2020 BAMB (Buildings As Material Banks) project, can be of high relevance for this building category.

Reversible buildings start with design. For commercial buildings, investors are the most important decision makers in the design phase. Are reversible designs more expensive to build than conventional designs? If so, how can people be convinced to invest in a reversible design in the first place? In this business case study, we looked into costs associated with reversible design, as well as potential financial incentives for the investors to opt for reversible design.

The market value of commercial buildings is determined in a fundamentally different way from non-commercial buildings. The value of non-commercial buildings is usually determined by their construction costs, while the value of commercial buildings is determined by the income they can generate through rent. This opens up an additional value proposition dimension for reversible buildings. If reversible design could lead into higher total revenue, and consequently a higher market value of the building, this may provide short-term financial incentives for the investors.

A common KPI (Key Performance Indicator) used in investment decisions is NPV (Net Present Value) – the revenue the building is expected to generate over its life span, minus the initial investment and running costs. Therefore the research question is defined to be: can reversible design increase the NPV of a commercial building?

2. Methods

In order to answer the research question above, a quantitative financial model has been developed based on a real-life commercial office building in Flanders. A time horizon of 50 years is used. After 50 years, ownership of the building will be transferred to the land owner. The building is constructed in Year 0 and ready for rent from Year 1. Two design alternatives, BAU and reversible, are included. In Year X ($1<X<50$), there is a need for drastic change of the building, due to reasons such as area re-development or demographic change. The probability of this event taking place in Year X is modelled. In response to this need for change, the building owner makes a rational decision to either decommission or transform the building. Costs and revenue streams are estimated, and NPV is calculated for each scenario using Discounted Cash Flow method. Finally, sensitivity analysis is carried out to identify parameters with the highest impact on the result.

2.1. Scenario definition

Two building design alternatives are defined to be BAU (Business As Usual) and reversible. The key technical difference between the two design alternatives is summarized in Table 1.

Table 1. Technical difference between BAU and reversible designs

	BAU design	**Reversible design**
Foundation	Foundations dimensioned for the original function of the building.	Foundations over dimensioned (deeper or larger).
Roof	Roof finishing made of traditional roofing and with aerated autoclaved concrete slabs.	Loose roof finishing with gravel ballast and prefabricated concrete hollow core slabs.
Interior walls	Gypsum cardboard fixed to a galvanized steel structure.	Demountable gypsum fiber boards on a screwed wooden structure.
Floor	Raised (hollow) floor made of adjustable pedals.	Hollow floor made of structural steel beams and precast concrete slabs.

In Year X, the building owner has the following options in response to the needed change: 1) Decommission. This can be either demolition or deconstruction. 2) Functional transformation from offices to high-end apartments. This involves only interior change (partition walls and floors). 3) Structural transformation by adding one extra floor on top of the office building. The technical feasibility of different options for each design is summarized in Table 2.

Table 2. Technical feasibility of change options for different designs

	Decommission	**Functional transformation**	**Structural transformation**
BAU design	Feasible (demolish)	Feasible	Not feasible
Reversible design	Feasible (deconstruct)	Feasible	Feasible

2.2. Probability model
The probability of the "need for drastic change" occurring in year X is denoted as P(X). Both log-normal distribution and Weibull distribution were used to model P(X) (see Figure 1). Since Flemish data was not available at the time of the study, age distributions of demolished non-residential buildings in other regions in North America [1] [2] and Western Europe [3] [4] were used as reference. The mean was set at 33 years which is the amortization period of commercial office buildings in Flanders. The spread was chosen to approximate the distribution found in the aforementioned literature.

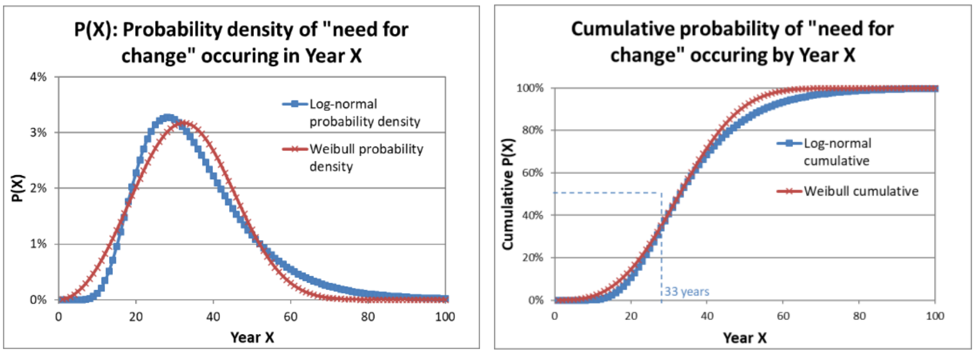

Figure 1. Probability model of need for change occurring in Year X.

2.3. Decision model
In response to the need for change, the probability that the building owner decides for a certain transformation or decommission option is denoted as P(Y). A decision tree model has been developed to estimate P(Y). The model assumes that the owner will make a rational decision, based on factors including market needs (for apartment or for more office space, with a conservative estimate), technical feasibility (Table 2) and financial calculations (transformation will be chosen only if the additional investment can be paid back before the end of the 50-year horizon). Results are shown in Figure 2.

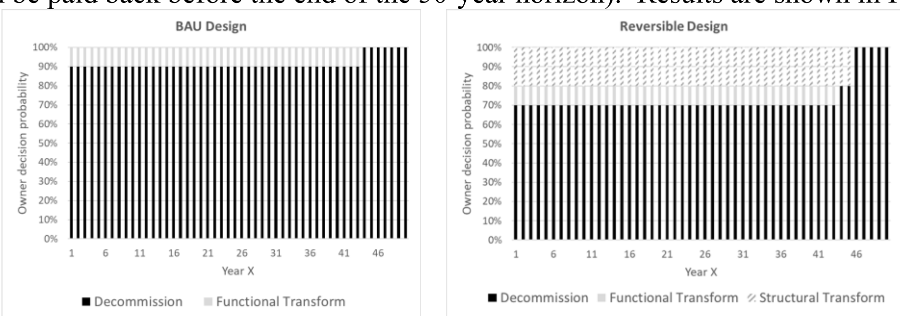

Figure 2. Probability of owner decision in response to needed change.

2.4. Cost structure and revenue stream

The various cost and revenue streams throughout the building life span are illustrated in Figure 3. Initial investment includes design and build costs. It is modelled as a one-off cost in Year 0. Maintenance and management costs are modelled as recurring annual costs as long as the building is in use. For simplicity, upgrade and replacement costs are also modelled as recurring annual costs, even though these are periodic costs in real life. Decommission and transformation costs are modelled as a one-off cost in Year X. Rent is modelled as a recurring annual income, as long as the building is in use.

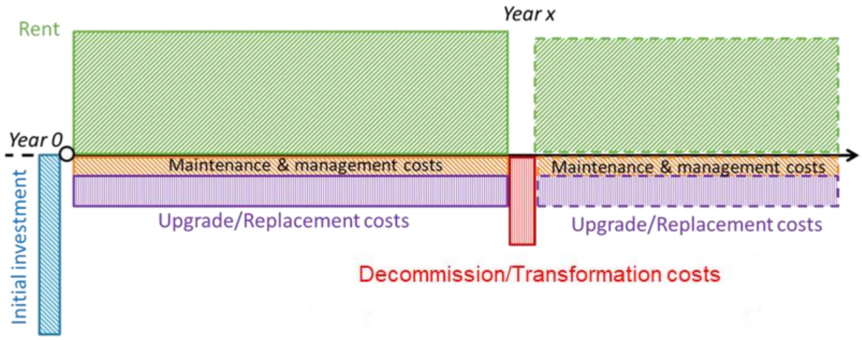

Figure 3. Simplified illustration of cash flow streams over time (not to scale).

2.5. Net present value and added value

Using Discounted Cash Flow method, net cash flow was calculated for every year till Year 50, based on the estimated costs and income. NPV was calculated for each set of building design (D) and owner decision scenario (Y), if a drastic change takes place in Year X: NPV (D, Y, X). The weighted average NPV of a given design is:

$$NPV(D) = \sum_{X=1}^{50} P(X) \cdot (\sum P(Y) \cdot NPV(D,Y,X))$$

where P(X) is the probability density of the need for change occurring in Year X, and P(Y) is the probability of a certain decommission/transformation decision being made by the building owner. Finally, the KPI is defined to be the "Added Value" of reversible design: Added Value = (NPV_Reversible - NPV_BAU) / NPV_BAU. Therefore, Added Value is expressed in %.

2.6. Sensitivity analysis

Sensitivity analysis is done by changing the value of a certain input parameter by +/-10% of its baseline value and calculate the subsequent change in the Added Value. For example, suppose the Added Value calculated with all baseline values is 9%, and a 10% decrease (-10%) in initial investment of reversible design results in an Added Value of 32%, then the subsequent change in Added Value is an increase of 23% (+23%).

3. Input parameters

Various data sources were used to ensure that the input parameters are representative of real-life numbers. Main sources include empirical data from Van Roey and BAMB pilots, literature and public database. All parameters are listed in present day values.

3.1. Initial investment

The initial investment costs used in the model take into consideration both materials and labor costs (including design costs), and exclude costs for preparation works, furniture and surroundings. The initial investment is estimated to be €7.6M for the BAU design and €8.1M for the reversible design. The difference result from foundation, roof, interior wall and floor designs (see Table 1).

Over-dimensioned foundation (deeper and larger) can bear a heavier building load and thus enables the structural transformation scenario of adding one extra floor to the office building. It slightly increases the initial investment.

In reversible design, a demountable roof solution, including loose roof finishing with gravel ballast and prefabricated concrete hollow core slabs, was chosen instead of aerated autoclaved concrete slabs as in BAU design. Part of the roof can be re-used in the structural transformation scenario, therefore reducing waste. The reversible roof also slightly increases the initial investment.

The reversible design chose a reversible interior wall solution prototyped in the BAMB pilots. This innovative wall solution consists of demountable gypsum fiber boards screwed to a wooden structure, whereas the BAU design uses gypsum cardboard fixed to a galvanized steel structure. The reversible interior walls can be re-used during functional transformation (office to apartment), resulting in cost savings and waste reduction. In this study, the technical performance of the prototyped reversible walls is assumed to be sufficiently high for the residential scenarios. The reversible wall actually slightly lowers the initial investment.

A demountable floor solution has been selected in reversible design. It consists of a composite hollow floor system, integrating technical services in the hollow floor made of structural steel beams and precast concrete slabs. The floor can be partially re-used during transformation, resulting in cost savings and waste reduction. The initial investment for the demountable floor system is higher.

Technical services (such as piping and cables) will be the same in the reversible design as the BAU design. It is difficult to have a "change-proof" design, since the layout of the technical services would be completely different in offices and apartments. Furthermore, the technical lifespan of piping and cables (15-20 years) is relatively short compared to the average time horizon of needed transformations. Therefore they will likely need to be replaced by the time of transformation anyway.

3.2. Use phase costs and revenue
Use phase costs include maintenance and management, upgrade and replacement. They are estimated to be €20-30/m^2/year. According to internal data and market data reported in 2018 [5], average rent rate for office buildings in the area is about €150/m^2/year, with an average vacancy of 9.6%; average rent rate for high-end apartments in the area is about €260/m^2/year, with an average vacancy of 15%. Use phase costs, rents and vacancy rates are assumed to be the same for BAU and reversible designs.

3.3. Decommission and transformation costs
Demolition contractors have estimated the fees charged to building owner to be €180k in case of demolition and €160k in case of deconstruction. The deconstruction fees are lower than demolition fees, since the contractor will be able to recover and sell some building components/materials as complementary revenue.

The functional transformation costs (from offices to apartments) are estimated to be €4.1M for a building with BAU design, and €3.7M if it has reversible design. The lower transformation costs of reversible design are attributed to material savings by re-using the reversible interior walls and part of the demountable floor system.

The structural transformation costs (adding one extra floor) are estimated to be €2.2M. This cost consists of the deconstruction of the roof, the construction of the additional floor level on top and the reconstruction of the roof.

3.4. Indices
An inflation rate of 2% is used in the study. The WACC (Weighted Average Cost of Capital) is taken to be 4.5%. Corporate income tax rate in Belgium is 34%.

4. Results
With the baseline values of the input parameters (as listed in the previous section), the weighted average NPV is €2.6M for BAU design and €2.85M for reversible design. Results differ slightly between the

log-normal and Weibull distributions, and an average was taken. Therefore, Added Value of reversible design in this case study is about 9%. In other words, at baseline parameter values (our best estimate to approximate real-life), reversible design can deliver a more positive NPV compared to BAU designs.

Sensitivity of the Added Value to different input parameters is summarized in Figure 4. It shows that the Added Value is highly sensitive to the initial investment of reversible design. It is also sensitive to the probability model, the decision tree model, and inflation indices. To a less extent, it is influenced by transformation costs. Furthermore, if reversible design could influence use phase costs or income (e.g. upgrade/replacement costs or vacancy rates), there will be a significant impact on its added value.

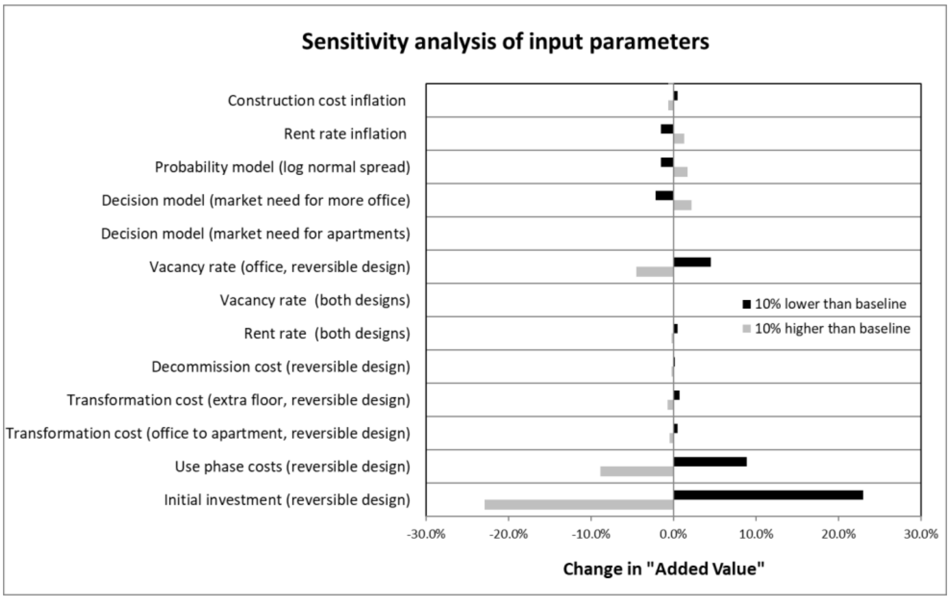

Figure 4. Sensitivity analysis of input parameters

5. Discussions

5.1. Value driver of reversible design

The model suggests that reversible design can increase the building NPV, even if it requires a higher initial investment and does not lead to savings during the use phase. What drives the added value of reversible design then?

Shorter-than-expected building service life poses a risk for commercial building investors. It gives uncertainty to the return on investment. As shown in Figure 5, although ideally the building will be rented out for the entire 50 years and achieve a maximum NPV of €6M, it is much more likely that the actual NPV will be lower due to early demolition in response to drastic change during these years. There is even some chance of capital loss if such change occurs in the early years. Figure 5 also illustrates the key value driver of reversible design: it reduces the overall investment risk by narrowing the spread of NPV probability distribution. In particular, it substantially reduces the risk of negative NPVs, i.e. loss of invested capital. Reversible design does so by providing additional transformation options (adding extra floor). The transformation option is more economically favorable than demolition, especially if the drastic change occurs relatively early in the building life, which could otherwise lead to capital loss in case of BAU designs. The maximum possible NPV is slightly lower for reversible design due to its higher initial investment.

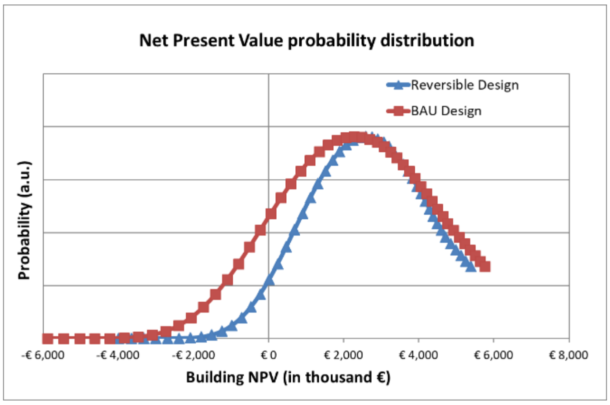

Figure 5. Building NPV probability distribution and impact of reversible design

5.2. Residual value

Residual value is often seen as a key financial incentive for reversible buildings. If at the end of life, the building is carefully deconstructed instead of demolished, the recovered materials and components could be sold to generate income. If we assume all materials can be recovered and sold at 15% of its original value, the maximal residual value of the building is estimated to be about €350-400k.

That is of course a highly optimistic estimate. The re-use market for building materials is primarily informal and very limited in size today. Unless the market demand significantly grows and the re-use value chain becomes much more mainstream, it remains very uncertain how much residual value can be actually realized. Furthermore, deconstruction is usually more costly than demolition. Even with a reversible design, deconstruction will likely require more time and more labor.

The model suggests that the decommission phase only has a marginal impact on the financial added value of reversible design. Even if the revenue from recovered materials will be able to cover all deconstruction costs and contractor profits, therefore decommissioning fee would be zero for the building owner, the Added Value of reversible design will only increase by about 2%. Hence residual value is unlikely to be a strong financial incentive for reversible building design.

5.3. Reversible design elements

The sensitivity analysis suggests that lowering the initial investment will effectively increase the financial attractiveness of reversible designs. Therefore it is worthwhile to carefully examine the different reversible design elements. Over-dimensioned foundation is only slightly more expensive (~1%) than BAU foundation. In return it enables more transformation possibilities (extra floor), which results in significant financial Added Value and environmental benefits. Reversible roof is slightly more expensive (~5%) than BAU roof. Part of the materials (e.g. insulations) can be re-used during transformation, resulting in moderate cost savings and waste reduction. Reversible interior walls are actually slightly less expensive (~1-2%) than BAU walls. They can be re-used during transformation, resulting in cost savings and waste reduction. Reversible floors, on the other hand, are substantially more expensive (~50%) than BAU floors. Part of the floor can be re-used during transformation to apartment, resulting in some cost savings and waste reduction. However, the financial business case for reversible floors is still negative, since the additional initial investment is high and definite, while the potential savings are moderate and may never be realized if the transformation to apartment does not take place.

In summary, the business case (both financially and environmentally) seems strong for over-dimensioned foundation and reversible interior walls, and moderate for reversible roof. The investment in reversible floor may need further justification (financially), by either reducing its initial cost, or increasing its benefits during the use phase and transformation phase.

5.4. Future work

All use phase costs and revenue are currently assumed to be the same for BAU design and reversible design. It is possible that reversible design could respond faster to user need change by e.g. easier spatial re-arrangement of the office space. This may have impact on vacancy rate, as well as use phase upgrade/replacement costs. Since the sensitivity analysis suggests that any impact on use phase costs and income specific to the reversible design could significantly influence the Added Value, it is worthwhile to further investigate the evidence of such impacts and how they can be modeled.

Local building stock demolition/transformation statistics, if available, should be used to review/improve the accuracy of the probability model and decision tree model.

The model currently assumes conventional ownership and transaction models. It will be interesting to simulate new business models, such as product service systems, and whether they can be used to lower possible barriers (e.g. higher initial investment) and further promote the market adoption of reversible buildings. Furthermore, integration the financial analysis with environmental impact analysis will provide a holistic business case for reversible buildings.

6. Conclusions

Commercial buildings are highly relevant for reversible designs. A quantitative financial model has been developed to assess the business case of reversible designs from the investor's perspective. A case study was conducted based on a real-life commercial office building in Flanders, while the methodology can be easily adapted for more generic use in other building types and geographical locations. The study reaches the encouraging conclusion that reversible design can already deliver added financial value, using available technologies and conventional business models of today. The core (financial) value proposition is investment risk reduction, by extending building service life and hedging against early demolition risk due to unexpected economic reasons. This may increase building market value and provide short-term incentives for wider market adoption of reversible designs. For actual adoption to take place, it is crucial that such added value can be recognized by the market. Therefore, real estate professionals (such as investors and appraisers) needs to be engaged from an early stage to validate the analysis and investigate possible integration into common building valuation methods. The study recommends that future research and development in reversible buildings give more attention to initial investment reduction and use phase benefits enhancement. This may be achieved by both technical innovation and business model innovation.

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