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Position statement

Scenario modelling for life-cycle analyses, an explorative use of conventional 3D BIM

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1. Introducing life-cycle analyses and scenario development

For long time, investors used to consider that most risk is related to the construction of a building (Clift 2003 p. 38). Risks result indeed from the uncertainty about for example ground and weather conditions, or resource prices and availability. However, since the time investors have been funding projects in new forms like public finance initiatives, their awareness has grown that there is even greater uncertainty about the operational stages of buildings. Should they for example anticipate rising vacancy rates or increasingly often refurbishments? Together with the understanding that buildings have a major impact on valuable material flows and on our vulnerable environment, such questions made grow investors' interest in the building's complete life-cycle.

For gaining insight in the life-long impact of initial design alternatives an environmental (LCA), financial (LCC) or other life-cycle analysis can be performed (Bull 1993; Ciambrone 1997). In such an analysis all impacts during every stage of the building's life-cycle are considered, including manufacturing, construction, maintenance, reparations, replacements, refurbishments, operation as well as deconstruction (CEN 2007). However, as the future becomes increasingly uncertain now technology and life-styles are chanting faster than ever, it is almost impossible (if relevant) to model each of the life-cycle stages and simply select the design alternative with the lowest total impact.

In addition to the size of an alternative's impact, the robustness of its impact is of interest when anticipating risk. It is in this search for the most futureproofed alternative that the management strategy Scenario Planning comes in view. Subjecting each alternative to the most various scenarios or 'imaginable futures', allows appraising the variability of their long-term impact. After such an appraisal, selecting the most robust alternative allows saying "I am prepared for whatever happens" writes the famous futurist Peter Schwartz (1991 p. 6).

Schnaars has noticed a growing interest in scenarios since "planners have recognized the importance of considering a number of plausible future environments [...], rather than relying on a single forecast" (1987 p. 105). More recently, Bishop et al. called scenarios "the stock-in-trade of futures studies" (2007 p. 5). However, in construction Scenario Development is rather rare (Goodier et al. 2010) and most life-cycle assessors consider scenarios as a kind of sensitivity analyses, e.g. about transport (Allacker 2010), technical installations (Debacker 2009; Woods & Bakshi 2014), operational water use and energy supply (Arvesen & Hertwich 2011; Blom et al. 2011; Dahlstrøm et al. 2012; Rasmussen et al. n.d.), maintenance (Xu et al. 2014), replacement (Allacker 2012) and the end-of-life (Debacker et al. 2013; Dewulf et al. 2009; Durmisevic 2006; Paduart 2012).

2. A conceptual BIM format for enhanced scenarios in life-cycle analyses

After a process of defining key drivers of change, the understanding how users and buildings cope with that change and stating it in terms of real and life-cycle options, scenarios have to be expressed in a numerical way. "While this quantification of scenarios is a more complicated representation than simple scenario narratives, they produce data that can be fed into computational models to generate simulation outcomes. Model simulations of scenarios enhance the scenario-planning process by producing quantitative estimates of the effectiveness of various strategies in different scenarios" explain Mahmoud et al. (2009).

Conventional 3D Building Information Modelling (BIM), for example in Autodesk Revit® could support this quantification efficiently. Its hierarchical project-family-instance-phase structure corresponds closely with the building-element-component-time approach found in many life-cycle analyses e.g. in Mithraratne and Vale (2004), Allacker (2010), Paduart (2012), Vandenbroucke et al. (2015) and Galle et al. (2015). Without explaining how scenarios relate exactly to the life-cycle calculations, the parameters of interest can be discussed by level. This discussion proceeds from the main scenario implementation categories defined by Pesonen et al. (2000), i.e. technological, contextual and value related implementations.

First, contextual information could be included in the project properties. These are valid for the whole building, but are not necessarily constant over the period of analysis. They can include the inflation rates, recycling and reuse rates, expected construction waste percentages, taxes, etc. Also the period of analysis can be a project property.

Second, at family or type level implementations could include material, labour and utility costs for all possible life-cycle stages. Moreover, it could consist of technical implications such as the disassembly and reuse potential of a component and its estimated service life determining its replacement frequency and potential resell value.

Third, information at the instances' level details further the technical implementations. For example instance properties can include factors adjusting the estimated service life (CEN 2008) in addition to their dimensional properties. Together this allows extracting a take-off including the total amount of all similar instances.

Fourth, modelling different phases (and naming them after the year of occurrence) can represent the transformations (or life-cycle options) considered in the scenarios. As a consequence, the quantities per type or family will change over the considered period of analysis. The model should facilitate tracking how many elements are added, removed and moved phase after phase.

Since BIM allows loading project properties, take-offs, counts and measurements directly from the model, it guaranties consistency throughout the assessment process. This information forms then reliable input for the life-cycle calculation in for example a separate spreadsheet (Kehily et al. 2013; McAuley & Kehily 2012). Table 1 gives a simplified example of such a take-off retrieved from BIM, listing in groups the instances of a space dividing wall. Relevant information for the life-cycle analyses include the instances' quantity, i.e. area $\boldsymbol{A}$, the year they were installed $\boldsymbol{y_i}$ (i.e. 'phase created') and the year they were removed from the building $\boldsymbol{y_f}$ (i.e. 'phase demolished'). In practice this table would be extended with the information from the three first levels discussed above.

3. BIM and the life-cycle management modelling of building elements

In the example take-off in Table 1 the instances are sorted by the year they were installed and removed so the total quantity is given for every possible sub-life-cycle during the 60 year long period of analysis. For a conventional building one would calculate and sum the individual life-cycle impacts of each of the five sub-life-cycles. However, although the building its life-cycle is modelled in BIM, from the take-off it is not possible to understand the life-cycle of the instances. Imagine a demountable dividing wall. It will be reused when it comes available and is needed elsewhere in the building. BIM cannot tell which quantity is reused every transformation since it is in the conventional 3D model only possible to add and remove elements per phase.

Table 1 This take-off of the various instances of the space dividing wall generated from BIM gives the quantities and other information for every possible sub-life-cycle from year y_i to y_f.

Element type	N	y_i	y_f	T [m]	L [m]	H [m]	A **[m²]**	V [m³]
Space div. wall	5	0	60	0,1	40	2,50	100	10
Space div. wall	3	0	15	0,1	40	2,50	100	10
Space div. wall	1	15	30	0,1	8	2,50	20	2
Space div. wall	3	30	45	0,1	40	2,50	100	10
Space div. wall	1	45	60	0,1	8	2,50	20	2

In order to extend the functional service life of an instance in the building and include all possible reuses, a VBA-script linked to a spreadsheet has been used to combine the given sub-life-cycles to longer ones. This mathematic transformation, performed for every element type, departs from the quantities that will be moved every transformation moment y_m. It is calculated as the minimum of the quantity that is removed and the quantity that is installed every y_m and collected in matrix M (Figure 1). Subsequently, for every possible sub-life-cycle of matrix Q (directly loaded from the take-off), considering the longest and earliest first, it is verified if there are enough elements to compose that sub-cycle of two separate intervals. If so, the amount that can be moved is added to the considered sub-life-cycle and reduced from the two adjacent intervals. These new quantities are stored in matrix Q' and the new move quantities are adjusted in matrix M'. This is repeated for every transformation moment and for every possible sub-life-cycle as long as there are moves available in matrix M'. As this script is fully parametric, the period of analysis and the number of sub-life-cycles can be automatically determined.

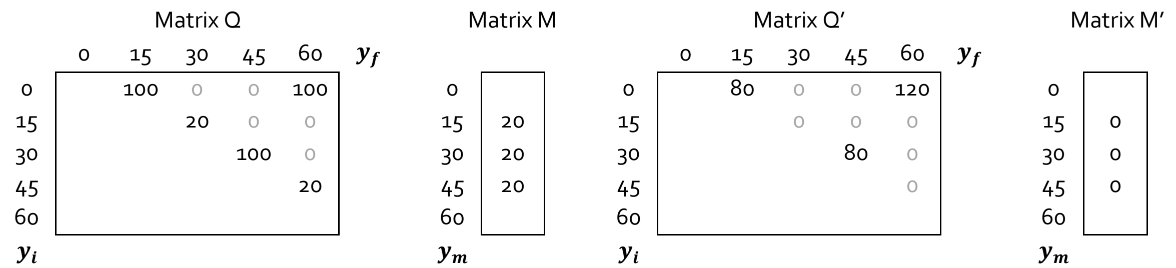

Figure 1 The quantities collected per sub-life-cycle are initially loaded in Matrix Q. However, they need to be transformed into Matrix Q' for accounting for reused and moved quantities every transformation moment y_m.

Now in matrix Q' the quantities $\boldsymbol{Q_{e\,sub}}$ linked to each sub-life-cycle from $\boldsymbol{y_i}$ to $\boldsymbol{y_f}$ include the reuse, and we know from matrix M the quantities $\boldsymbol{Q_m}$ related to every move at year $\boldsymbol{y_m}$ we can calculate and sum for example in a life-cycle costing analysis the net present value $\boldsymbol{NPV_e}$ with equations (1), (2) and (3), wherein $\boldsymbol{PV_{e\,sub}}$ is the life-cycle cost per unit of element $\boldsymbol{e}$ from $\boldsymbol{y_i}$ till $\boldsymbol{y_t}$, and $\boldsymbol{PV_m}$ is the present value of $\boldsymbol{C_m}$ the costs to move one unit of element $\boldsymbol{e}$ at $\boldsymbol{y_m}$.

$$\boldsymbol{NPV_e = \sum_{e\,sub} Q_{e\,sub} \cdot PV_{e\,sub} + \sum_{m} Q_m \cdot PV_m} \tag{1}$$

$$\boldsymbol{PV_{e\,sub} = \sum_{j} \sum_{t=0}^{y_f - y_i} C_j \cdot \left(\frac{1 + r_i}{1 + r_d}\right)^{y_i + t}} \tag{2}$$

$$\boldsymbol{PV_m = C_m \cdot \left(\frac{1 + r_i}{1 + r_d}\right)^{y_m}} \tag{3}$$

With $\boldsymbol{C_j}$ all relevant and significant life-cycle costs of element $\boldsymbol{e}$,
$\boldsymbol{r_i}$ the inflation rate and $\boldsymbol{r_d}$ the real discount rate.

4. Discussion

For finding how robust the life-cycle impact of design alternatives is, modelling consistently the operational stages during which various scenarios are effectuated is of increasing importance. It is after all during these stages the life-cycle benefits of reuse, recycling and resale of elements are expected. If we do so, scenarios are no sensitivity analyses with constant parameter values. Actual transformation scenarios introduce changing quantities over the period of analysis.

Very few life-cycle analyses with changing quantities are discussed in literature. One example is the Gandhi neighbourhood Design for Change case study (Paduart et al. 2013). In this study scenarios include for example the recurrent merging and splitting of apartments. With the introduction of such transformations the researchers' gained understanding of the value of using demountable elements in comparison to other measure for increasing the design's transformational capacity like the versatility of the lay-out, generality of the load bearing structure and the clustering of functions. This lead to the advice of a well targeted use of adaptable elements.

Concluding from the example presented in this paper, the inability of conventional 3D BIM to express the life-cycle of individual elements is considered as a crucial weakness when integrating scenarios in life-cycle analyses. Whether this is caused by the fact current models are not semantically rich enough (Shen et al. 2007) or by the mismatch between traditional standards of measurement and BIM objects (Kehily et al. 2013), this finding confirms the idea brought forward by van Nederveen and Gielingh (2009): "The new business concepts require a life-cycle modelling approach in which individual components and materials play a central role. Buildings are considered as temporary configurations of these components and materials. The functional life of buildings, which strives for higher and sustainable end-user value, becomes detached from the technical life of building components and materials, [...]." Therefore, recent advances in 4D BIM should be explored.

5. References

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