The Hendrickx–Vanwalleghem design strategy

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Abstract

The optimisation of structures and materials is a justifiably popular engineering topic. Contemporary research is concentrated, among others, into cost minimisation, structural efficiency and intelligence, in compliance with environmental and social preservation. As a counterpart this paper puts the accent on the time dependent aspect of constructions, such as the life cycle cost, the possibility to make (non-) structural changes and recycling or reuse of building material. In search of an optimisation of this 'dynamic' efficiency of constructions, a design strategy has been developed at the Vrije Universiteit Brussels (Departments of MeMC and ARCH). This strategy is presented here. It considers the temporal character of constructions from the first sketches onwards.
Keywords: adaptability, reuse, design strategy, construction kits, generating system, temporal/temporary.

1 Introduction

In society buildings have been - and still are - designed in terms of *end states*. The moment the first sketches are drawn, the construction's finality is planned or denied. Because of their *static nature*, which they acquired ab initio, most buildings are not suited to meet the demands of a quickly changing society. As a result many building components end up as waste or are brought back in circulation by means of expensive and consuming industrial processes. Changing functions, quickly evolving living and building trends, the amount of new materials and improved techniques… are some mutations the built environment *has* to go through and *has* to provide appropriate answers to. Although humans

WIT Transactions on The Built Environment, Vol 85, © 2006 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/HPSM06061

have to cope with an unpredictable future, full of uncertainties, there is one universal ‘constant’: the environment always changes! Hence, a *sustainable* built environment requires *a dynamic concept*; a step-by-step redesign process of gradual changes in which no end states or final goals can be defined [2].

The strategy “Hendrickx–Vanwalleghem” [3] includes this dynamic view on the built environment. By designing *adaptable construction systems*, which are compatible with each other, a dynamic – and by this a sustainable – answer can be given to an unexpected and unpredictable future. These construction systems are made of a minimum number of basic elements and a set of combination rules. They allow the conversion of each artefact to a different configuration, by means of adding, removing or transforming the basic elements which it is made of. It offers a high potential of recycling and (direct) reuse. The outcome can be compared with the ‘Meccano’ building set, which, in this view, encloses all materials and techniques, and is applicable to all scales.

Hendrickx and Vanwalleghem proposed a set of standardisation rules, which they called a “generating form and dimensioning system”, The generating system is a central concept in the design strategy, in the sense that it ensures full compatibility of form and dimensions between all basic elements. The rules are translated into a *fractal model*, based on basic forms, such as the square, the inner circle and its diagonal, and a dimensional range using the operator “multiply or divide by 2” (*Fig. 2*).

2 The Hendrickx–Vanwalleghem strategy

Hendrickx and Vanwalleghem developed a “dynamic design strategy” (further called “Hendrickx–Vanwalleghem strategy”). It allows for the design of *flexible construction systems*, based on a minimal number of elements and combination rules.

The design strategy is explained in *Fig 1*. It consists of 4 layers. The lower layer is characterised by a *material solution*, using 2 design tools, shown in the upper *conceptual* layer: the *generating form and dimensioning system* and the *theoretical design catalogues*.

The text hereafter explains the set-up of the design strategy, starting with the material solutions (layer 4).

2.1 Layer 4: Adaptable material solutions

According to European standards [4], a durable house is designed for a life cycle of 50 years. It is easy to understand that such constructions will undergo radical transformations and repairs during this extensive period. The “Hendrickx–Vanwalleghem” design strategy has consequently been developed for constructions subjected to these transformation processes.

In *Fig.1* the reader can see how a minimal habitation unit can be transformed into alternative configurations. This minimal habitation unit provides its user(s) with basic functionalities. It can be expanded from its core, according to evolving possibilities of user(s) and/or the building site. This principle has been successfully applied in (developing) countries, such as India, as it takes into account a gradual development of the users and the possibility to perform reversible changes. Of course, such processes should make use of simple and cost effective building methods.

2.2 Layer 3: Adaptable construction elements

As a consequence of previous argumentation, construction elements must be developed to be easily adaptable and reusable. This should be done not only for the non structural elements but also for the load bearing ones, such as walls, floors, foundations, columns, beams (*Fig.1*) and, even more important, the connections. Nevertheless, all these elements can be deconstructed into very simple "*basic elements*".

2.3 Layer 2: Compatible construction kits

The basic elements can be compared to the letters of an alphabet: they do not carry a semantic meaning. The basic elements can be combined in different ways and form a variety of construction elements, which in the actual comparison can be considered as words. Three types of basic elements can be discerned:

- *line elements* (one-dimensional)
- *plane elements* (two-dimensional)
- *volume elements* (three-dimensional)

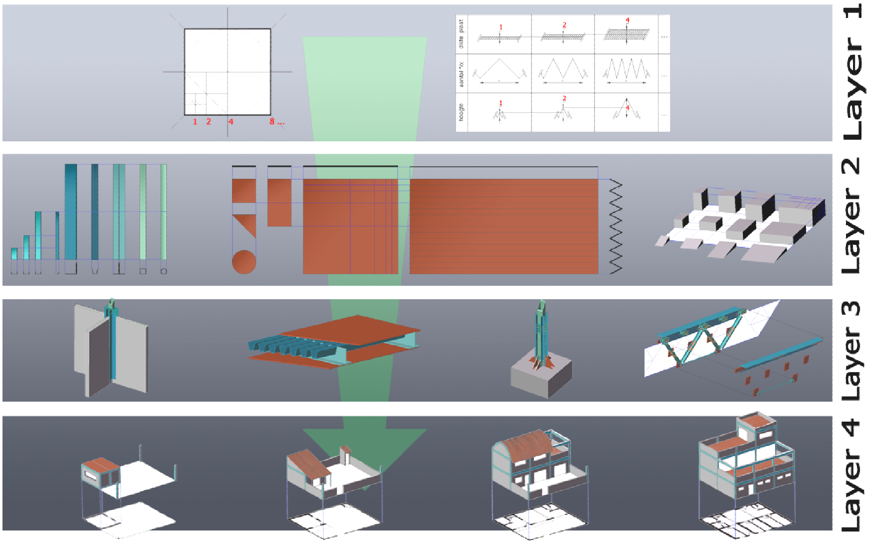

Figure 1: The Hendrickx–Vanwalleghem design strategy.

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Point elements (zero-dimensional) can be categorised in the previous classification: e.g. bolts can be considered as scaled volume elements.

A "*construction kit*" is defined as a grouping of a FEW simple basic elements aiming at the assembly of one or more adaptive construction elements. One must be aware that the building of a complete construction will very often require several construction kits. It is thus absolutely necessary that all basic elements found in the same construction kit or even another one, be compatible with each other. The establishment of explicit standardisation rules is here for stringent.

2.4 Layer 1: Development of adaptable construction systems

2.4.1 Design tool 1: a generating form and dimensioning system

Using their own developed design tool, called a "generating form and dimensioning system", Hendrickx and Vanwalleghem proposed a set of standardisation rules. It is a central concept in the design strategy, in the sense that it ensures full compatibility of form and dimensions between all the simple basic elements.

Hendrickx and Vanwalleghem presume that any tangible element, in any construction phase, can be approximated with a minimal diversity of basic forms. They have chosen the *square*, its *diagonals* and the *inscribed circle*, due to an important property of the former, i.e. its orthonormality. This makes sense since right angles are found in many material solutions and certainly in the area of construction.

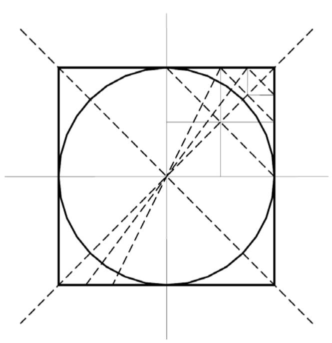

Figure 2: Model of the generating system.

To make effective use of the proposed system, the set of basic forms should be provided with basic dimensions. In order to achieve optimal flexibility and combination, the basic elements should have the same dimensions. If differences are unavoidable "Hendrickx–Vanwalleghem" proposed to solve the problem using *the rules of either halving or doubling*. Both are the result of an easy mathematical manipulation and create a geometrical series. Halving is easy if one uses flexible elements: they can be folded. Starting with a square with side 'x' one finds: *x*, *2x*, *4x*, *8x*, *16x*…

The fractal model in *Fig. 2* can be projected on all materials and all scales and thus can define the basic elements for each material type. Grouping ALL possible variations within a chosen set of basic elements is named as a "*construction system*". The types of basic element (first order elements) are defined by both their form and their constitutive material, as these define how basic elements should be joined and combined into basic elements of a higher level. Here the attention should be drawn to the fact that a construction system is not an object, but rather a set of entities, i.e. smallest elements of the system, between which predefined relations exist. Those are the dimensional and formal rules imposed by the generating system. The concept of "*construction kit*" can thus be redefined as a rational selection of SOME basic elements out of one ore more construction systems. The objective is to generate one or more flexible constructions and their constitutive parts.

2.4.2 Design tool 2: theoretical design catalogues

An aid to the development of construction systems is achieved developing theoretical design catalogues. This development is carried out in the following way.

In a first step each material solution, or more precisely each of its construction elements, in whichever phase, is objectively and verbally described based on characteristics, strengths and weaknesses. Each characteristic has one or more parameters as a counterpart, all bracketed between predefined limits. This delimitation, for each parameter, is done at the level of the *entities*. Considering that all artefacts are measurable and can be depicted, most of the parameters can be visualised with simple symbols or pictograms and be categorized in different series. If a graphic representation is not wanted or impossible, a short verbal description will be sufficient. Through interpolation and/or combination of the outer elements in the series all variants can be achieved.

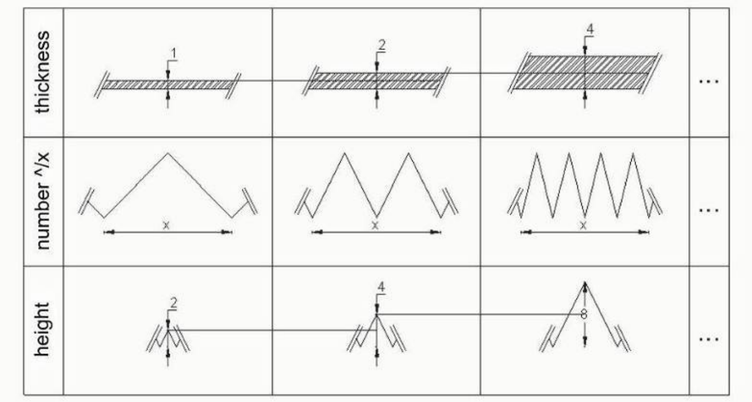

Figure 3: Theoretical design catalogue of a load bearing corrugated plate.

This can be illustrated with a simple construction element. The bearing capacity of a steel corrugated plate, subject to transverse loads – e.g. used as a roof element – can be described with three parameters: *its thickness, the number* *of waves per unit length and the height of the waves* (or also the predefined form of the wave). These parameters can be entered into series by defining the extreme values. A thin plate is the opposite of a thick one: this means that there is a limit for the ratio thickness/span. The number of waves per unit length and the height of the waves are limited by plate thickness and fabrication process. All variants should lie between the thus defined limits.

With arithmetic and geometric calculation rules changes in each series can be described; every value of the parameter thus gets its place within the series. Whether the succession of elements is continuous or discontinuous has no importance, at least on the theoretical level. But practically seen stepwise variations are preferred: they reduce the number of values and more easily achieve the goal of using a *minimal number of (standardised) basic elements*. The adopted geometrical "rule of the game" stems from the fractal model in the generating system, which can easily be seen in following sketch:

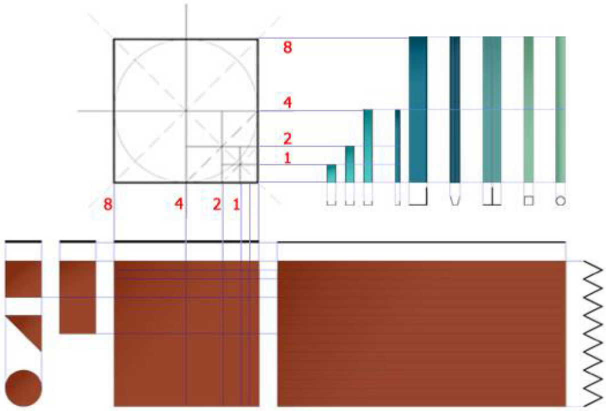

Figure 4: Compatible basic elements.

If all series of individual parameters are grouped, any historical, actual or future artefact can be theoretically described by a series of lines or vectors which intersect in a common point. Variations or new solutions are found by translating one or more lines through the intersection point.

A theoretical design catalogue is thus established, combining and juxtaposing elements. The emphasis has been put on "theoretical", as in practice not all combinations are possible or technically sound. This means that they are erased in the *practical* catalogue.

This approach can be applied to a whole construction. As the bracketing of an entire construction is difficult, the preference is given to deconstructing it into physically and non-physically observable elements, without forgetting to keep in mind the global context. For example, the maximum height of a building is often defined through ridge height or roof slope of adjacent constructions.

The concluding result is a fan of design catalogues, each one based on combinations of selected parametric rules. They allow to describe any artefact, existing or not, through translation of one or more series.

The above presented strategy matches perfectly with the idea of *open industrialisation*, wherein a minimum of construction elements, belonging to several construction systems and distributors, based on the same design rules, can be combined together to form multiple (adaptable) projects [5].

3 Temporary character of constructions

The awareness of the limited life time of our heritage is ever increasing; slums are demolished, old train stations are replaced by prestigious ones, offices are refurbished and monuments are carefully renovated or the object of restoration…

Still professional developers and real estate owners pay little attention to the temporary character of a construction: even during the study and the drawing phase this aspect is often forgotten or even simply ignored. The point is that if you want to face changing uses during the life time of the construction, static solutions will make transformations extremely difficult if not impossible. It could happen that some structural elements still perform in a satisfactory way, but the owner will often prefer to demolish and start over. This causes a lot of debris. Consequently, the actual society is missing a dynamic design strategy, allowing transformations and adaptations during the life cycle of a construction.
The “Hendrickx – Vanwalleghem” design strategy takes these characteristics of temporality and adaptability of constructions into account, from the first sketches on. It allows every construction part to transform into another configuration by adding, deleting and transforming basic elements of the same system and combining it with elements coming from other. One of the consequences is that so-called “dry connections” are used: bolts and nuts, screws, click-systems… [6, 7].

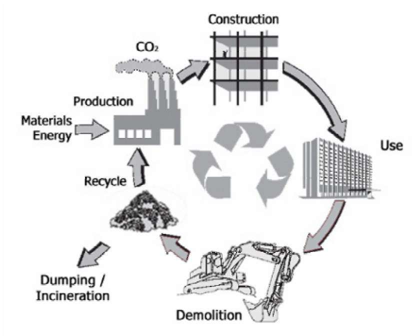

Figure 5: Actual model of the life cycle of a construction.

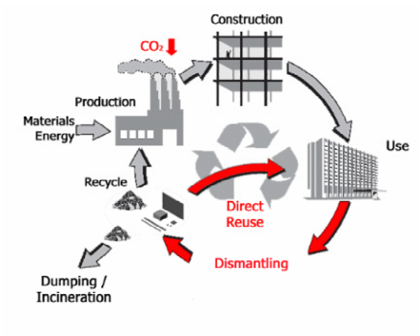

Figure 6: Proposed model of the life cycle of a construction.

Damaged basic elements can be reused allowing small transformations, even in fields where the structural, i.e. load bearing properties, are less important (furniture, window frames…). Hence the "total life cycle cost" of the elements will decrease.

4 Modular versus generating

The main asset of a modular construction system is an economical one. Thanks to (modular) standardization, simplified and cheaper prefabrication processes are made possible, which consequently speeds up the construction phase. Modular construction systems are also known as flexible. However, this is not without any shortcomings!

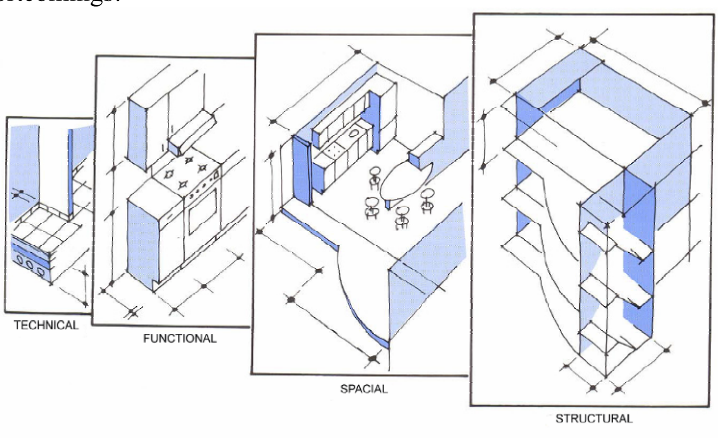

Figure 7: The 4 design levels [8].

Changing a module or unit is excluded, because it is has been technically and structurally denied. Adaptability – and by this the designer's freedom – is therefore limited to the addition and reduction of fixed modules. A common employed module is '*the foot*' (in the horizontal plane). This module is approx. 30cm and is rightfully successful as a functional, ergonomic and spatial unit. But it cannot be used at all levels of the design: for technical dimensions it is often too large, for structural purposes too small (*Fig.7*). A multi-modular grid provides an improvement; i.e. a superposition of modular design grids with a different module – related to the respective design level (structural, spatial, functional or technical). Design at different levels is thus possible, but not without possible conflicts. Using an arbitrary or no mathematical relation between the module sizes dimensional problems occur where different grid lines intersect (*Fig. 8*). [8]

The standardisation rules of the generating system are based on a *fractal* model (*Fig.2*). Thanks to a single operator (divide or multiply by 2), switching to different design levels is always possible, and this without jeopardising compatibility between each basic element. A generating system thus allows the development of (multi-) modular systems, but with the additional property that they can be used with different design scales.

Furthermore, it is not “the module” which is standardised but the (dimensional) modifiable basic elements from which it is composed. The latter is the key difference with modular construction systems.

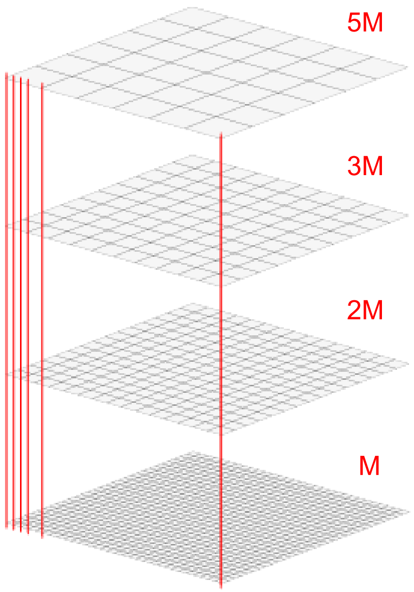

Figure 8: Multi-modular grid.

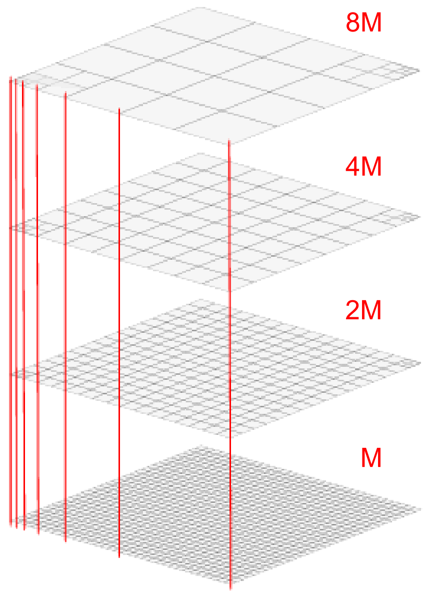

Figure 9: Generated compatible design grids.

5 Conclusion

The Hendrickx-Vanwalleghem design strategy offers a sustainable answer to the optimisation of ‘dynamic’ characteristics of the construction world. Thanks to its explicit standardisation rules, it maximises adaptability and reuse possibilities during the construction’s entire life. Full compatibility between basic elements of the same construction kit and elements belonging to others, makes an unequivocal generating system even more efficient than modular systems.

References

[1] De Wilde W.P., Conceptual design of lightweight structures: the role of morphological indicators and the structural index. *Proc. of 3rd International Conf. on High Performance Structures and Materials 2006*, ed. Wessex Institute of Technology, United Kingdom, 2006.

[2] Hendrickx, H., Vanwalleghem, H., Sustainable Urban Development. *Local Agenda 21 in Development Perspective*, 48p. http://home.tiscali.be/momentumcongressen/Paper%20Van%20Walleghem.pdf
[3] Hendrickx H., Solutions derived from natural processes harmonising nature and material culture. *Proc. of the 1st Conf. on Design and Nature 2002. Comparing Design in Nature with science and engineering*, ed. C.A. Brebbia & L.J. Sucharov, Wessex Institute of Technology, United Kingdom and P. Pascolo, Universita degli di Udini, Italy, 10p. 2002.
[4] European Committee for Standardization (CEN), *Eurocode – Basis of structural design: NBN EN 1990*, pp. 23-26, 2002.
[5] Henrotay, C., Research report. *A generally applicable building system for shelter in emergency situations. ,* Vrije Universiteit Brussels, Brussels, Belgium, 2005
[6] W. Debacker, *Sustainable development of the material culture approached by system thinking*, Master's dissertation, Vrije Universiteit Brussels, Brussels, 2003.
[7] C. Henrotay, *Sustainable Development. A general description and research of its application towards the material support in emergency situations*. Master's Thesis, Vrije Universiteit Brussels, Brussels, Belgium, 2003
[8] De Troyer, F., Naert, N., Grids: help or obstacle?. *Building with prefab concrete: design guide,* ed. FEBELCEM / FEBE, Brussels, Belgium, *12p.*