Technical detailing principles for the design of adaptable and reusable construction elements in temporary dwellings

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Abstract

Nowadays, global awareness of the impact of human activities on the natural world is more relevant than at any other time in history. The construction sector has been influencing and modifying the natural world in an undeniable way. Buildings are constructed in response to specific needs of a contemporary society and afterwards often demolished as a result of a change in these primary needs. It is clear that unsteady factors of life and society contribute to the flux of materials used in all types of construction, including renovation, adaptive reuse, deconstruction and every other kind of building effort. To reduce the consumption of valuable materials and the depletion of natural resources, waste management of constructions needs to be taken into account in the early stages of design. This requires innovative design strategies that anticipate an eventual demolition and provide versatile and adaptable structures.

Research in adaptable/reusable architecture currently lacks an organizing, and systematic theoretical basis. "4Dimensional Design Strategy" (4D), developed by H. Hendrickx and H. Vanwalleghem (Solutions derived from natural processes harmonising nature and material culture. *In Proc. of the 1st Conf. on Design and Nature. Comparing Design in Nature with science and engineering*, WIT, UK and P. Pascolo, Universita degli di Udini, Italy, p.10, 2002) proposes a dynamic and systematic view on the built environment. 4D is a guide to design adaptable and compatible construction systems, by which a variety of adaptable and reusable construction components and constructions can be composed. It offers high potential for recycling and (direct) reuse.

The development of adaptable and reusable construction systems requires a number of practical design rules. A preliminary analysis of existing flexible buildings systems revealed important preconditions for the practical detailing of adaptable buildings. Using the 4D design strategy, this paper formulates additional technical detailing principles for adaptable constructions. The emphasis will be put on the integration of technical service systems, waterproof connections, and thermal and acoustic insulation. These principles will be further detailed through a characteristic case study: temporary dwellings.
Keywords: waste management, adaptability, reuse, 4D, construction systems.

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1 Introduction

Unanticipated forces and emerging circumstances have compelled change in architecture for ages. Yet, most buildings are constructed as if they would serve unchanged for countless decades [5]. The contemporary buildings are not designed to be adapted, or to be dismantled easily. Building and living trends, technological and socio-economical evolutions cannot be predicted without great uncertainty. This makes it difficult to foresee and manage how our future buildings ought to look. A moment will come when these buildings do not meet the requirements – set up by individuals and society – anymore. Because they are designed as 'static' products, they will not be adapted easily or not without a significant price tag. Despite significant service life remaining in the fabric of the building, its location, particular use, materials, systems or other aspects of its original design can lead to a decision for demolition rather than reuse or adaptation of some kind [1]. This often means that most of the building components will end up on the waste pile.

Adaptability and reuse of construction elements are two combining ways to anticipate this uncertain future, but these require a number of practical regulation rules for the design of construction systems. A preliminary analysis of existing flexible building systems [4] revealed important preconditions for practical detailing of adaptable buildings. Flexible, adaptable and reusable constructions systems can only be achieved when design is equally focused on the general construction system as well as the construction detailing!

The dry connections, which are indispensable for dismantling and adapting constructions, demand special consideration during design. Therefore, attention has to be paid to the integration and detailing of technical service systems, waterproof connections, and thermal and acoustical insulation.

2 Design strategy

The "4Dimensional Design Strategy" (4D), proposed by H. Hendrickx and H. Vanwalleghem encloses a dynamic view on the built environment [3]. 4D supports the design of multiple construction systems while enabling the adaptability, compatibility and reuse. Out of each construction system a variety of adaptable and reusable construction components and constructions can be composed. Each construction system is 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 that 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" [6].

3 Case study: temporary dwellings

3.1 Construction kit for temporary dwellings

Since the Flemish Ministry of social housing is carrying out a big scale reconditioning of its entire heritage a concept was developed to make use of removable transitory habitats to (re)allocate underprivileged people for a span of 3 to 6 months. Based on the 4D strategy a construction kit has been designed by Vrije Universiteit Brussel (VUB – dept. MeMC) [6] to formulate an answer to the temporary nature of this issue. All basic elements are interchangeable and resizable, making them the construction elements for various dwelling types. Multiple reuses of its basic elements will drop the emboded energy of the components drastically and will reduce the amount of building waste [7].

3.2 Building system temporary dwellings

The considered construction kit is composed of 4 major types of simple construction elements:

1. *bearing frames* (end and intermediate frames),
2. *horizontal girders* (basic structure and girders),
3. *sandwich panels* (floor, roof, side and end walls),
4. *dry connections* (bolts and lock devices).

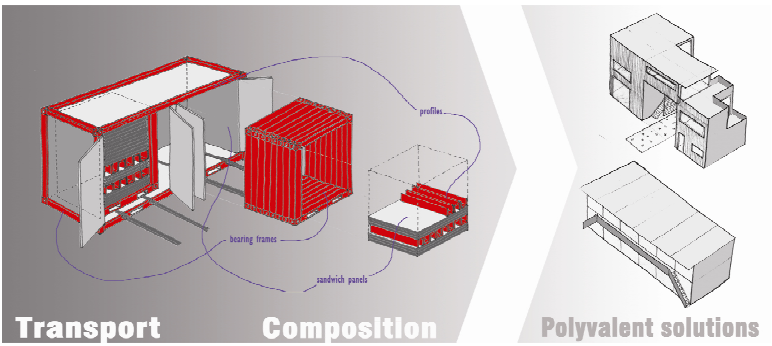


Figure 1: Conceptual drawing of the used construction kit.

Each of them is made of 'neutral' basic elements such as *profiles* (one-dimensional), *plates* (two-dimensional), hollow and plain *volumes* (three-dimensional). Once they are assembled together they acquire a constructive meaning! Thanks to the generating system, each basic element is compatible

with any other – and thus interchangeable. The above mentioned construction components are hereby resizable and transformable as required using a minimum of base elements.

To allow 'intermodal' transport (train, truck and inland waterway) the design was oriented to a 20' ISO container wherein the bearing frames, horizontal profiles and sandwich elements of 5 equivalent 20' units are compacted to each other (Figure 1). This allows low cost transport and storage. In addition, use of energy and natural resources is significantly reduced [7].

4 Detailing of temporary dwellings

The temporary nature of the situation requires dry connection systems, which allow easy dismantling and reuse of the basic elements. Every possible connection made in the construction of the dwellings needs to be considered and carefully designed to develop buildings systems that meet contemporary regulations. Subsequently, the detailing of adaptable constructions, such as the described temporary dwellings will need additional attention.

4.1 Electricity and water supply

Regarding the relations between construction and technical services these can be distinguished into three main categories:

- entire separation between construction and services,
- partial integration of constructions and services,
- entire integration of constructions and services.

An important reason to seek an *entire separation* or a *partial integration* of the construction and the technical services concerns the difference in life span between the construction and its building services. Buildings can serve 60 to 80 years on average, while technical facilities often have shortcomings after a period of only 20 years [8]. By (partially) separating the services from the construction the opportunity is given to replace failing technical installations instead of considering a (partly) demolition of the building.

In addition, it is necessary to search for flexible service systems to achieve adaptability for the temporary dwellings. Wiring and piping need high accessibility and flexibility to respond to changes in configuration.

The temporary nature of the dwellings demands low labour-intensive, easy transportable and reusable solutions for both sanitary and electrical facilities.

The *vertical distribution* can be designed in three principal ways (Figure 2). The technical ducts can be provided either through the floor and ceiling panels, either through the bearing structure of the dwellings, or through the wall panels. The first option is found most convenient, when working with a *wet cell* introduced inside the dwellings, equipped with sanitary facilities, a kitchen, and an internal technical shaft distributing the plumbing and ducting.

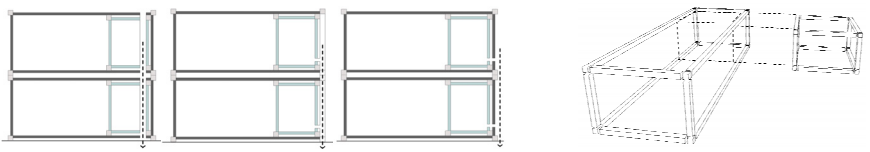


Figure 2: Technical shaft inside sanitary box.

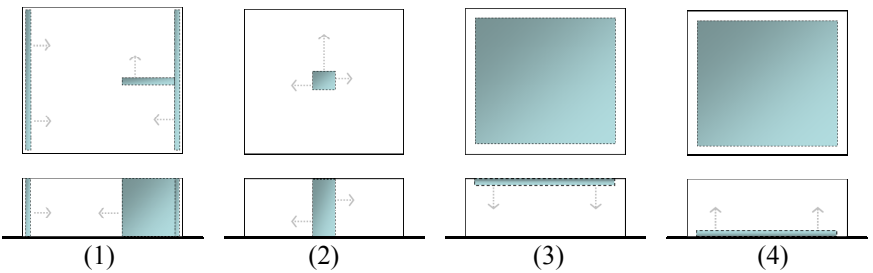


Figure 3: Different types of horizontal electricity supply: (1) Wall system. (2) Shaft system. (3) Ceiling system. (4) Floor system.

Since all facilities are clustered in this unit, composed of the 4 former types of construction elements, no additional plumbing has to be provided in the dwelling. These (small) prefabricated spaces will speed up the construction, since they only need to be plugged into the interior surrounding where electricity and water supply is available. To optimize transport and reuse of these boxes, two wet cells fit into a 20' ISO container.

The *horizontal* electricity *supply* can be distinguished into four main distribution systems (Figure 3(1)) Distribution from the walls; 2) Distribution from a vertical shaft; 3) Distribution from the ceilings; 4) Distribution from the floors.

Bearing in mind minimal costs, minimum of interventions, and quick and easy set-up of the distribution system, two solutions are presented for the temporary dwellings. A first proposition, a ceiling system, distributes electric ducting by cable channels fixed to the ceiling, dividing both lamp and plug sockets over the room. A second option provides the plug sockets below the walls (wall system). In both cases, the electric wiring consists of plug/lamp sockets between connected wire fragments. This solution offers high flexibility, since electrical distribution can be easily changed, there where needed [9].

4.2 Water and wind tightness

To guarantee the realisation of water and windproof constructions, different realisations in correlation with the set-up period of the temporary dwellings are taken into account. Long term disposition (1-6 months) of the temporary dwellings have to meet higher requirements, than dwellings used for a very short period (days-weeks). Aspects such as (dis)assembly, cost and construction speed are dependant of the span of the set-up period and will influence the nature of the roof solution.

For a short set-up period, low cost and quick assembly are prescribed. These dwellings can easily be covered by means of PVC coated polyester sheets. These covering sheets are given versatile opportunities by introducing loops, reinforcing strips, additional flaps and connection points at the sheet ends.

The loops are used to join different sheet strips together (offering covering for different dwelling typologies) and to stretch them by means of additional belts. Flaps guarantee the water tightness of the connection (Figure 4).

The flaps and connection belts assure in addition a tightly fastened connection with the main structure (Figure 5).

For long time application (until 6 months) an extension of the basic construction kit is offered. The basic roof panels are substituted by specifically designed roof panels. These sandwich panels are manufactured with an inclined plane to avoid water accumulation on the roof surface. The watertightness of the roof connection of these panels is obtained by integrating an additional layer – a watertight membrane - in the sandwich panel composition (Figure 6(a)).

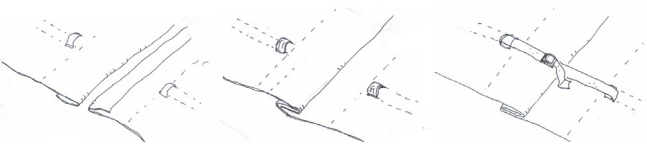


Figure 4: Joining together different canvas strips.

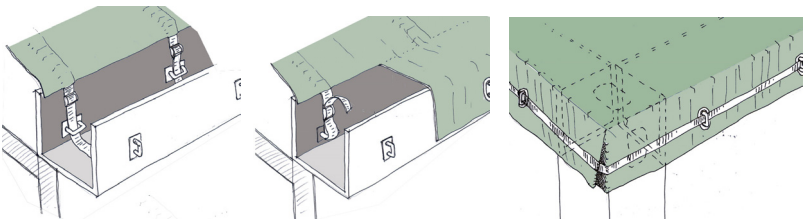
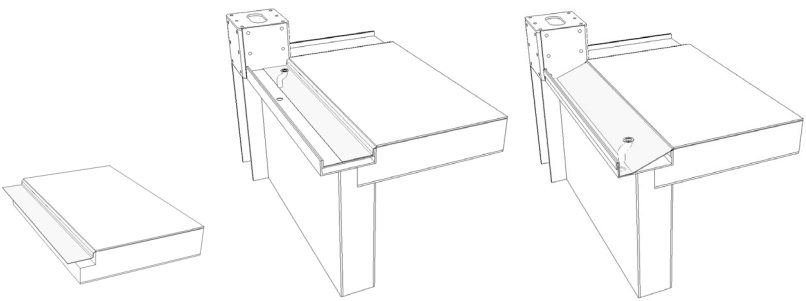


Figure 5: Connection with the main structure.



(a) (b) (c)

Figure 6: Panel system allowing watertightness of the roof construction: (a) roof sandwich panel with incorporated membrane; (b) roof solution with additional gutter; (c) roof solution without additional gutter.

The membrane is longer than the width of the panels. This is done to prevent water infiltration inside the construction of the dwellings. Dependant on the need of an external drainage gutter, the membrane provides the opportunity to actualise different configurations. A first option consists of adding an external gutter, which drains the water through a gutter pipe (Figure 6(b)). In a second option the drainage is realised by using openings in the membranes in which gutter pipes are being clamped (Figure 6(c)).

Both roof compositions can entirely be executed by means of dry connections (bolts and fasteners) to make the dismantling and reuse possible in practice.

4.3 Acoustic and thermal insulation

In the proposal for the basic construction kit, the temporary dwellings are built up by filling up an external skeleton with self-bearing sandwich panels. These sandwich panels are composed of 0,6 mm steel top covering at both sides of the panels, compressing a 70 mm thick layer of a hard insulation material (PUR). The requested thermal insulation norms in Belgium (K45) can be put into practice by means of relatively thin wall panels, through which lightweight structures can be realised. However, it is this lightweight nature of the temporary dwellings that causes problems in terms of acoustics. Using light steel construction systems, acoustic insulation depends on several parameters [10]:

- The sound insulation performance of low frequency ranges is proportional to the *mass* of the building elements.
- *Disconnection* of the different elements composing the wall structure ameliorates the acoustical performance.
- *Low stiffness* of constructions improves the acoustic insulation performance.

Regarding the case study of temporary dwellings, optimalisation of air sound insulation of the dwellings is not achievable by increasing the mass or the thickness of the construction; operating in the framework of easily transportable structures, light and manageable panels are required. In addition, since the thermal insulation of the dwellings is realised through a hard insulation material inside the sandwich panels (PUR), it is difficult to decrease the stiffness of the construction with the use of these sandwich panels. On the other hand, improving the sound insulation by double-layering the walls and applying an acoustic disconnection [11], introduces additional elements to the construction kit, which raises the degree of complexity of the assembly and slows down the building process.

It is clear that taking in consideration the advantages as well as the disadvantages of these alternative approaches, a selection has to be made depending on the context in which the dwellings will operate.

For a short period set-up, when low acoustic performance is required, the basic construction kit (composed with self-bearing sandwich panels) can still be used, without taking special measures. When high acoustic performance is requested, the general composition of the wall elements has to be modified. A secondary frame with additional (sandwich) panels has to be introduced inside

the basic construction, providing a double layered wall composition. This secondary frame structure is connected to the primary structure by means of insulation strips, to reduce sound air paths.

On the other hand, the type of the thermal insulation has to be reconsidered. The structure of PUR insulation is made of enclosed cells, which reduces sound absorption [11]. Soft thermal insulation materials, such as rock wool, have better acoustic properties and should be considered for application in this case.

5 Conclusions

To obtain constructions that can adapt to changing circumstances, constructions systems need to be developed so they can respond to these changes. A construction kit has been designed for temporary dwellings to meet this constraint. Further detailing of this kit was needed to ensure the feasibility of the dwellings.

The degree of integration of the buildings services in the primary structure needs to be regarded in terms of flexibility and adaptability. A (partial) separation is required to avoid (complete) demolition when building services 'fail' and to increase the adaptability to different dwelling configurations. A wet cell is introduced inside the temporary dwellings, providing the supply of electricity and water through an integrated shaft and clustering the fully equipped kitchen and sanitary functions in one or two units. Furthermore, flexible and dismountable alternatives are given to distribute the electrical cabling inside the dwellings.

The need for dry connections to dismantle and adapt the dwellings involves problems in terms of water and wind infiltration at the roof surface. For short time application, a quick and low cost solution based on sheeting is considered. Through addition of loops, reinforcing strips, flaps and connection points on PVC strips, different connection types, can be realised. For longer application an extension of the basic construction kit is offered. A specific roof panel was designed, attaining water and wind tightness by means of additional layering of the roof panels. Although all proposed solutions can be dismantled, a watertight roof surface is achieved!

This paper revealed problems when considering the acoustical performances of the construction kit. Lightweight structures with quick assembly and acoustic insulation seem to be two different aspects of the temporary dwellings that demand for opposite development. When quick assembly and easy transportable dwellings are needed, a basic construction kit built up by sandwich panels is offered. When higher acoustic is requested, acoustic insulation is achieved by applying several separate plates with an acoustic disconnection. The offered solution needs however further development.

The detailing principles that were set up for the described temporary dwellings can and will be extended to the framework of more permanent dwellings.

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