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Design Support for revisable buildings with focus on visualizing and simulating transformation capacity during initial design phase

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Abstract

Instead of designing buildings as static structures with one end of life option (demolition) circular buildings should be open upgradable platforms, transformable structures that can accommodate changing use and technical requirements across their whole Life Cycle. Rather than destroying buildings while adapting them to fit into new requirements, it should be possible to answer new requirements without demolition. In other words, in order to keep buildings in an economic loop through their whole life cycle building designs should guaranty high transformation capacity of buildings and their structure. Design of transformable buildings involves deliberation of spatial and technical aspects of future building and represents a multi-criteria optimization strategy. This strategy has impact on all design phase form transformable spatial configurations analyzed conceptual design phase moving towards optimization of technical solutions and their impact on transformation scenarios during final design phases. Transformation capacity of a building indicates the ability of a building design to deal with functional, technical or physical changes without generating material waste. A design with a higher transformation capacity implies lower environmental impact from a building configuration. Previous studies have described parameters that influence the transformation capacity and proposed models to assess a design accordingly.

The right combination of parameters for each design decision making level impacting transformation capacity is being tested and used as a base for a software framework.

Besides little remains known about how the impact of design decisions on the transformation capacity could be visualized and simulated. This paper will present, the conceptual framework and algorithms developed that calculate transformation capacity (relevant for the conceptual design phase) and provide an interactive feedback to the designer during initial design phase of the building.

Because it is extremely beneficial to give immediate feedback to know how good each design decision is, the framework has been developed in dynamic extendable way which gives it the ability to understand and analyze data/models that come from different sources with different level of details. That offers high potential to easily integrate the framework with different technologies and use it during different project phases. The framework is developed using metaprogramming techniques to give high flexibility to define/modify its behavior in runtime which makes it efficient solution to wide range of complex problems. With a focus on the preliminary design stage, the framework was tested to validate its efficiency and effectiveness Expected outcomes of this research are insights about how visualization and simulation techniques could be employed using dynamic extendable framework to provide insight into the transformation capacity of a conceptual building design.

Keywords: Transformation capacity, reversible buildings, virtual simulation, visualization, circular building, metaprogramming, automated integration.

Background

Accurate evaluation of transformable structures needs integration of knowledge that come from different sources. The knowledge which describes different constraints (structural, economic, environmental...) has different semantics, form and level of details. These constraints are also different based on the location of the structure (different cities have different environmental, economic constraints and different regulations) and the purpose of the project. That requires developing a very flexible framework that accepts information of different form/level of details and adapts to change of requirements smoothly.

Easy Integration with the used technologies to extract information and leverage their capabilities saves a lot of time and errors. That offers high potential to go hand in hand with stakeholders to guide them to the optimum solution by offering immediate feedback to each design step. Any good design of a software framework should also integrate easily with future technologies and needs, which puts a lot of complexities and demands on that design to integrate with the unknown.

Simulation of design decisions during initial design stage to support design of buildings with high transformation capacity

Very often buildings are seen as finished and permanent structures. They are carefully designed around short-term predictions of one building use. Real-estate developers warn that the existing building stock does not match with the continuous and ever increasing changes in market demand. This difference in supply and demand resulted in the huge vacancy. Only in the Netherlands, according to the national Planning Institute, the society has a burden of 8.5 million m^2 of vacant office space without a use value (PBL 2013).

Ultimately modern buildings are designed and built based on conventional mono-functional and liner concept of use, consumption, demolition and waste disposal. They are not built for long life by concept of upgrading and adaptability to dynamic social, economic and climatic activities but for demolition. (Durmisevic, Pasic& Colakoglu, 2015).Based on analysis of barrier for transformation of buildings and the Flextool model of Durmisevic (2007) criteria that have impact on the transformation capacity have been defined. Transformation of the building in its full form involves considerations about spatial transformation of the building and technical transformation of the building. (Figure 1)

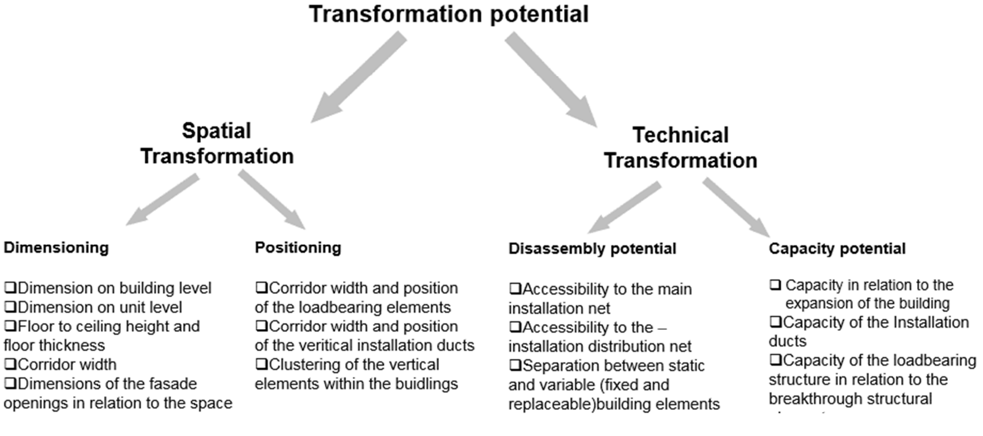


Figure 1: Parameters defining Transformation potential model Durmisevic 2007

Parameters defining Spatial transformation are (1) dimensions (for example: dimension of building block, spatial units and spatial ability to accommodate different functions) , (2) the position of fixed elements (for example core elements that can form a physical barrier during transformation as for example vertical communication, loadbearing span and corridor (including escape route).

Parameters defining the Technical Transformation are (1) the capacity of the core structure to support transformation of function, (2) the disassembly of variable parts of the structure as for example disassembly of infill system, partitioning walls, etc.

Transformation Model determines level of spatial reversibility. Parameters that determine Transformation Modelsin particular volume dimension, position and capacity are presented in figures 2, 3 and 4.

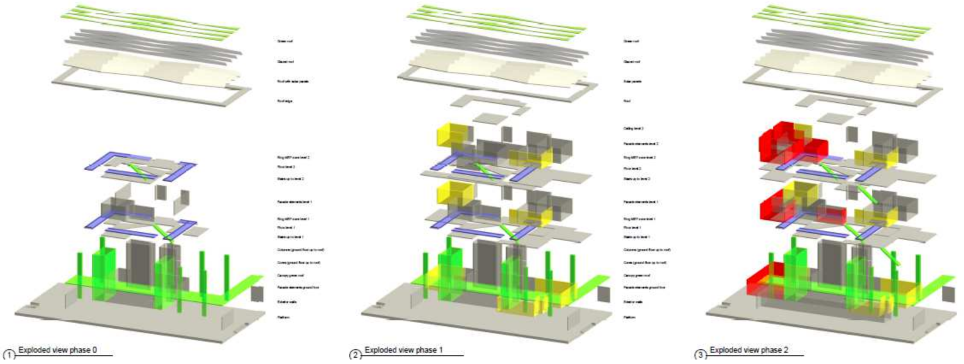


Figure 2: Analyses of building block Volume dimensions that are compatible with different use scenarios

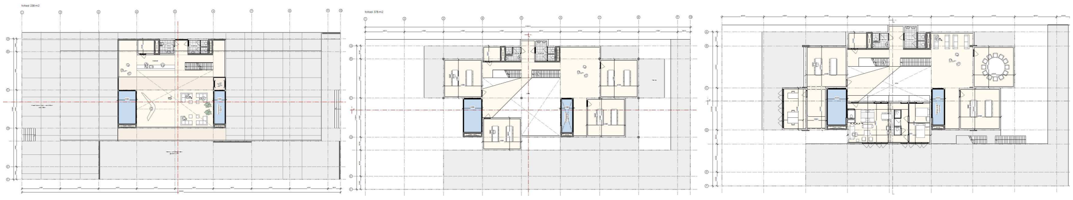


Figure 3: Position of the core elements that is not restricting number of use options,

Core design: Core is integrated base element, a minimum needed to provide for structural stability and facilitate climate, energy and comfort for different use scenarios.

This most fixed part of the building needs to have capacity to facilitate transformation form one use scenario to another without demolition and waste creation. Core needs to have capacity to carry loads and provide space for services for desired upgradability.

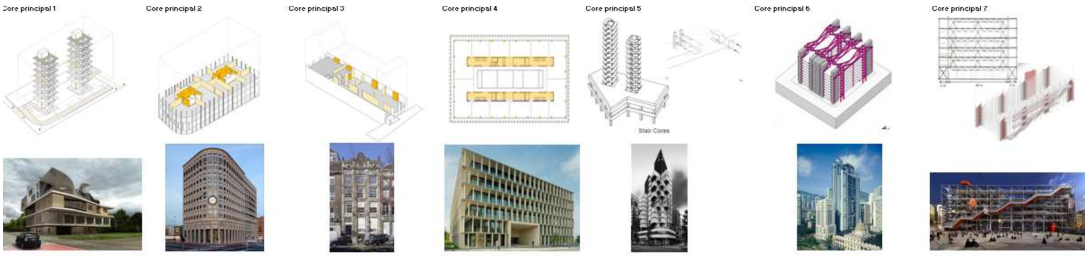


Figure 4: Core capacity and different core principles resulting into different transformation models with different space configurations.

Transformation rules integrated into virtual simulator

Virtual Simulator will provide feedback to the architects during initial design stage (conceptual design). The tool will inform the architect about spatial capacities of the first concepts. Many architects have started to use sketch up during conceptual design phase when defining the spatial volumes and spatial configurations of the building. Virtual simulator will inform the architect in each step of volume analyses about the transformation capacity of the proposed solutions. As design progress further towards the materialisation the model will be imported into a Revit and more detailed evaluation of reversibility of building can be done in Revit. Test software has been developed for the virtual simulator using one of the transformation models developed through International design studios in 2016 (IDS 2016). The model has been used to define rules and associated algorithms that provide real-time feedback about Transformation capacity. The software platform is compatible with BIM platform and allows transfer of parametric and other data form conceptual design phase to detailed design phase developed in BIM (Revit). The rating of Transformation Capacity TC in this test model is set as TC=1 the ideal situation. This means that all transformation options form figure 6 are possible. TC> 0, 8 more than 80% of options are possible TC>0, 5 less than 50 % of options possible, TC>0, 3 less than 30% of options are possible, TC=0 no transformation options possible. Two rules have been integrated into the test software.

Rule one had to do with the analyses of spatial capacity of a building block (usually made as a first volume during spatial and volume configuration analyses). Designer starts creating one transformation models by choosing the type of core to work with. As for example chain core positioned in the middle (figure 5) integrating stability elements, installation ducts and communication.

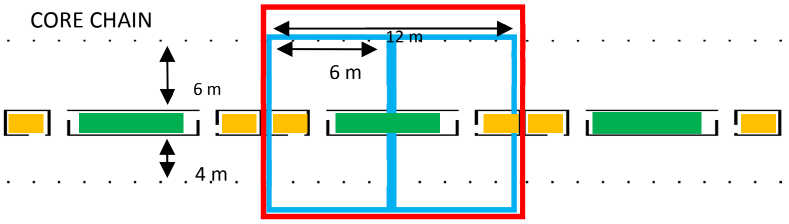


Figure 5: Transformation model used to develop test software to calculate transformation capacity (IDS 2016, Maastricht)

Based on a chain core form figure a transformation model has been developed that house two types of offices, three types of housing and two types of classroom configurations.

The test model is based on this core principle in combination with total volume 12x12m that offers 7 multifunctional transformation options (figure 6) having thus TC=1. If for example volume would become dipper than 12 m the quality of housing would be reduced due to the diminishing of natural light and would become unfeasible. That means that the number of spatial configurations would be reduced 5 options.

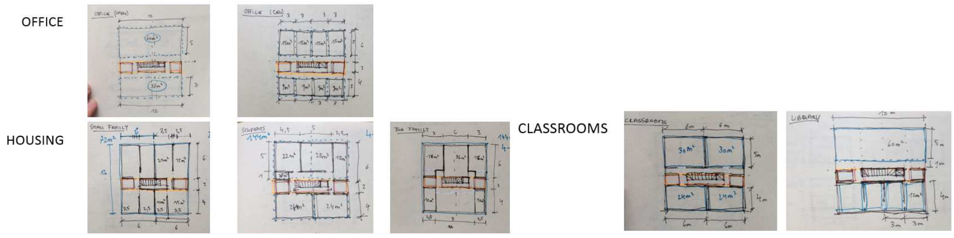


Figure 6: Ideal transformation model with chain core in the middle of 12x12 volume accommodate two office, three housing and two education use scenarios

Rule two deals with choosing of the construction span and construction system.

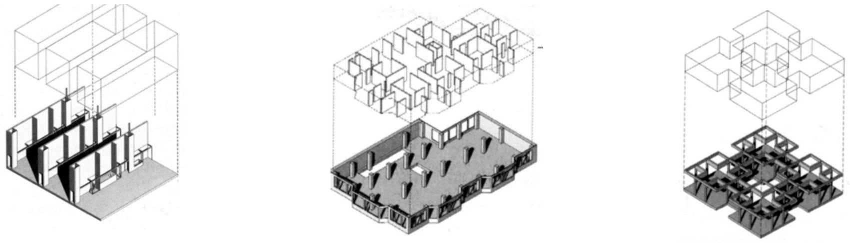
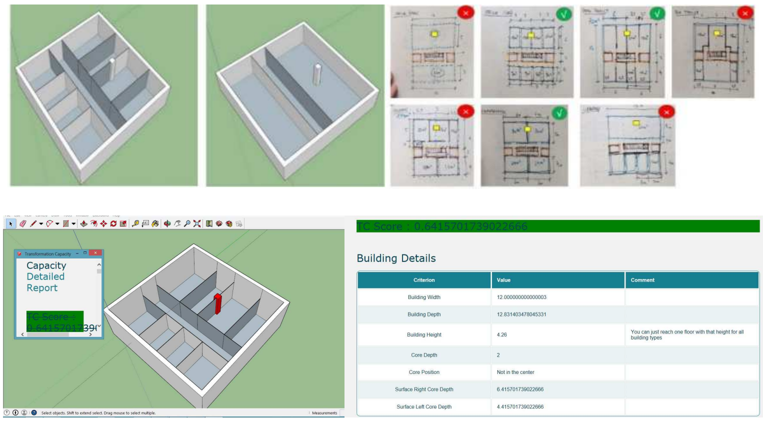


Figure 7: fixed versus flexible, Leupne 2002

If the panel wall structure is chosen in combination with the construction span of 6m than number of possible use scenarios would be reduced by 50%.

Algorithems of the rules : First, the software detects automatically the structural elements, the partitioning elements (demountable) and the core. Based on that information, it evaluates the dimensions of the building, the location of the core and the distance from the core to the edge of the building. Second, it removes partitioning elements (demountable) but preserves the structural elements. Then it tests the possibility of transforming the cleaned model (after removing demountable elements) to the ideal models. If the location of any structural element is not in a required free space of an ideal model, then the transformation to that ideal model is possible. Finally the number of possible transformation options is counted.



Select objects. Shift to extend select. Drag mouse to select multiple.

TC Score : 0.6415701739022666

Building Details

Criterion	Value	Comment
Building Width	12.000000000000003	
Building Depth	12.831403478045331	
Building Height	4.26	You can just reach one floor with that height for all building types
Core Depth	2	
Core Position	Not in the center	
Surface Right Core Depth	6.415701739022666	
Surface Left Core Depth	4.415701739022666	

Figure 8. virtual simulator using sketch up and feedback provided to the designer

The proposed software framework

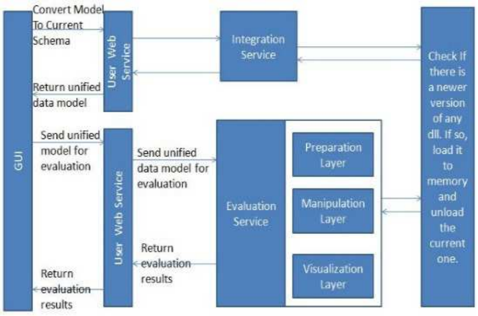
A good transformable buildings software framework should be mainly responsible of four main functions which are Integration with different data models to extract building information, organizing the information in a suitable data structure, applying some rules to evaluate the building and Visualizing the result efficiently.

As shown in Figure 11, a framework has been designed with two main user services which are the integration service and the evaluation service. The integration service is responsible for extracting information from different data models and provide a unified data model (user defined schema). It is developed as a standalone service to offer high flexibility for two-way integration (from any data model to reversible building schema and vice versa). That is very helpful especially when working on non-rich data models (like sketch up). With two-way

integration, it is possible for users to convert a non-rich data model directly to a rich one (BIM) and avoid building the model totally from scratch on different technologies.
The evaluation service is responsible for evaluating the building. The input to this service is the unified data model produced by the integration service. The evaluation service compromises three loosely coupled layers which are preparation, manipulation and visualization. The preparation layer is where the relations between objects are deduced automatically and built. The output of this layer is a well-organized data structure (each object knows its attributes and its relations with other objects). The manipulation layer is where the actual evaluation happens. It contains a rule based engine which applies user defined rules on the unified data model to evaluate the building. The output of that layer is evaluation result which is the input to the visualization layer. The visualization layer is where the evaluation result is prepared and put in a format for visualization purposes. Providing high flexibility to that framework needs deferring the actual implementation to be defined in runtime by allowing the user to define his desired behavior, so meta-programming and model driven design are adopted to offer that behavior. As shown in figure 8, the framework has admin service that allows users to define their desired behavior through a web based graphical user interface (GUI). The user defines his needs as a metadata and the framework which contains a code generator automatically translates that metadata to a compiled code through the generation service (figure 10). Normal requests for evaluating buildings are as shown in figure 9. The user requests to evaluate his model by sending the model to the user service. User service automatically calls the integration service internally to convert any data model to the latest user defined schema. Then the user service calls the evaluation service with the unified data model returned from the integration service and return the returned result to the user. Any updates to the metadata during runtime causes the framework to generate everything again and replace old dlls with newer dlls, so the system is always updated to latest user needs. The separation between the integration and the evaluation service makes it possible to call each service directly which is the desired behavior after developing a standard schema for reversible buildings.

Applying the framework in preliminary design

Sketch up has been used as the GUI by developing a plug-in on it. The plug-in is just used to send the building model to the framework and visualize the returned results. In the integration layer, mathematical algorithms are used to recognize objects and extract building information from just sketch up points and lines and convert that model to the user defined schema. In the preparation layer, AI algorithms are used to understand the relations between building's spaces/objects. In the manipulation layer, the rule based engine applies the evaluation rules. In the visualization layer, the report is built which contains information of the areas of errors, what the errors are and recommendations to fix these errors. Finally, the Sketch up plug-in receives the returned result from the framework and then highlights the areas of errors by giving it a red color and provide the user with a TC score and a detailed report which both help in improving the design.



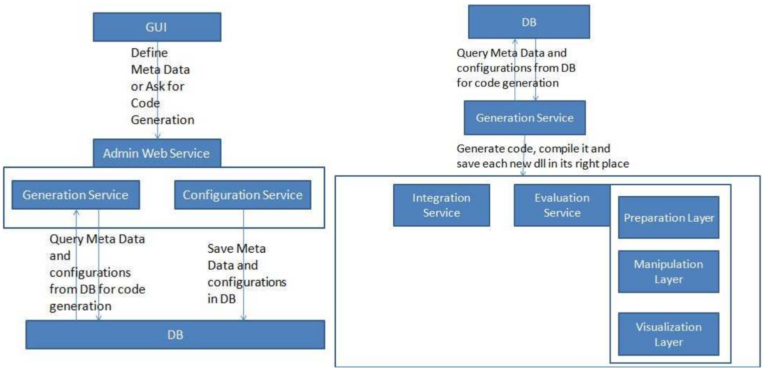


Figure 9. Above Admin Service right Generation Service, down Request user service after developing standard schema

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