OPEN CONFIGURATION MODEL FOR COLLECTIVE HOUSING BUILDING STRUCTURE: GRAPH MODEL

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ABSTRACT

The collective housing buildings are usually inflexible in the exploitation phase because of inflexible building structure. Inflexible structural model is composed of components and subsystems, more or less joined together into complex relations and fixed connections. Such physical relations stand as a limitation for elements to be replaced at the end of its service life and for the structure to be upgraded. Changes at the building level of 'static' systems are related with time and money consuming by long transformation processes, significant energy and material lose and enormous amount of waste production. The term transformation is introduced for dynamic changes in building structure on spatial, technical and material level. After each use phase, systems' configuration should be assembled to indicate building suitability for transformations according to new changing requirements. Open configuration model, based on independent and exchangeable components and subsystems, applied for more permanent building parts like load-bearing structure, enclosing, services' systems, may become the solution for the new dynamics in building structure. We will consider more specifically how controlled hierarchies, based on independency and systematization of elements in different technical levels, provide a context for flexibility in buildings. Technical composition of systems' configuration will be presented as a graph model. Graph model is a description for systems' configuration model to support systematization of structural elements into open hierarchy assemblies, based on edges between nodes and clusters. The cluster is an assembly of nodes (components) that perform the same function. The 'edge' is a demountable connection between nodes and clusters.

Finally this research is about systems' configuration model for building structure with special focus on: 1) more flexibility of long-lasting building parts 2) integrated model based on coordinated relations-edges, between assemblies-clusters 3) more transformation capacity of integrated systems and components; 4) configuration ability to transform according to demountable joints.

Key words: systems' configuration, systematization, housing building structure, edge-node and cluster, graph model

Introduction

Building Structure as a Solid Model

Most of the massive buildings in Europe are demolished or planed for demolition because of building unsuitability for spatial and technical transformations. The conventional buildings do not support dynamic changes of users' needs nether the technical systems' upgrading according to different life span of its components. The building structure is built by traditional 'cast in place' construction techniques, prefabricated elements and/or industrialized components and subsystems, as mixed systems where elements (components and subsystems) rely on each other by mixed functions and fixed connections [9]. Adaptability process of strongly dependent parts in building structure is related with high rehabilitations costs, important demolitions and waste production. Key obstacles for successful transformation and upgrading process of existing structures are:

- Inflexible load-bearing structure (cross-bearing system).
- Fixed integrations between load-bearing and non-load-bearing parts of the structure.
- Inflexible and old installations' systems.
- Lack of accessibility to the components that have shorter life circle and should change with more frequency.
- Physical and functional dependences in the building structure and labyrinth of interfaces that create complexity for components' assemblies to transform.

When we examine the composition of complex artefacts we start from the configuration of elements and connections between them. Main findings from analysis of the resent apartment buildings in Europe based on 'open building' principles and strategies [3, 6] for flexible and adaptable residential buildings, show the importance of flexible and demountable systems' configuration for more permanent building parts [8]. From the other side, in the existing buildings we find the

strong dependency conditions in massive composite structure. Existing housing structures and future projects are defined as systems' configuration model of four principal functions and corresponding technical systems: load-bearing, enclosing, interior partitioning and installations systems, where elements are put together into different levels of dependency conditions [9]. Design for flexibility and disassembly of the new systems' configurations and upgrading of existing hosing models will be questioned according to two criteria. First to be considered is a dependency conditions between assemblies in building structure, its lower composition elements and the relations between them. Second is the potential benefit of more independent structural parts to be used for planning new retrofitting scenarios for existing structures upgrading. First to be applied is 'assembly hierarchy' for massive structure decomposition according to hierarchical technical levels and components systematization. It tells us that a unit on a higher level in the hierarchy is composed of elements we find on the lower level [2].

Definition of the Building Structure as a Systems' Configuration Model

The building structure is usually inflexible in the exploitation phase because of inflexible configuration, fixed connections and lack of accessibility for the components that should change with more frequency. In the 60' 'Open Building' designers have been started to design flexible structure based on load-bearing system and envelope system together with engineers, to build structure according to the needs of the particular design [6]. The main feature of 'open' systems' configuration is flexibility for transformations of different assemblies. Design of housing had become the design and building of more flexible systems' configurations for building structure. Transition from solid model to 'open' model underlined new era for systems' assembly according to different building functions. Different technologies started to be developed for load-bearing systems and envelope systems. In the further development of the technology for industrialized housing systems, the systems' production was divided into the elements of primary construction and those of the secondary construction or façades, which made things easier in coordination between building structure and building infill. Further development of the building industry was defined by full prefabrication and thus a complete industrialization of all elements belonging to primary and secondary construction. This kind of systematic approach for building parts into systems' configuration has been approved after the WWII in former Yugoslavia as well. Figure 1 presents the systematization of elements according to four main building functions in IMS systems' configuration. Building structure is composed of: IMS concrete skeleton frame; building envelope; interior partitions; and service systems. The red line shows that building foundation and basement floor are reinforced 'cast in place' parts and belong to one hierarchical level. The blue lines show the independent technical assemblies. IMS skeleton frame is on the second level which means that is first in the hierarchy to be assembled. III level are independent assemblies for façade, roof, interior partitions and services. On the IV level are placed different components, subsystems and systems of different

assemblies from the third level. Evidently, most post-war social housing buildings deal with no energy efficient systems, neither with basic service systems. All green fields are actually missing in most of the massive housing buildings. It can be observed that there are no 'interior' systems beside the interior partition walls. But, the way technical systems are assembled into hierarchy assembly allow for the IV level to integrate additional systems for the sustainable rehabilitation of the existing buildings. An analysis of the building structure as the systems' configuration of elements and the relations between them is applied to describe how its parts are put together (what parts and type of connections). New retrofitting scenarios may be planned according to disassembly potential of more independent parts without disturbing other systems' assemblies in the structure.
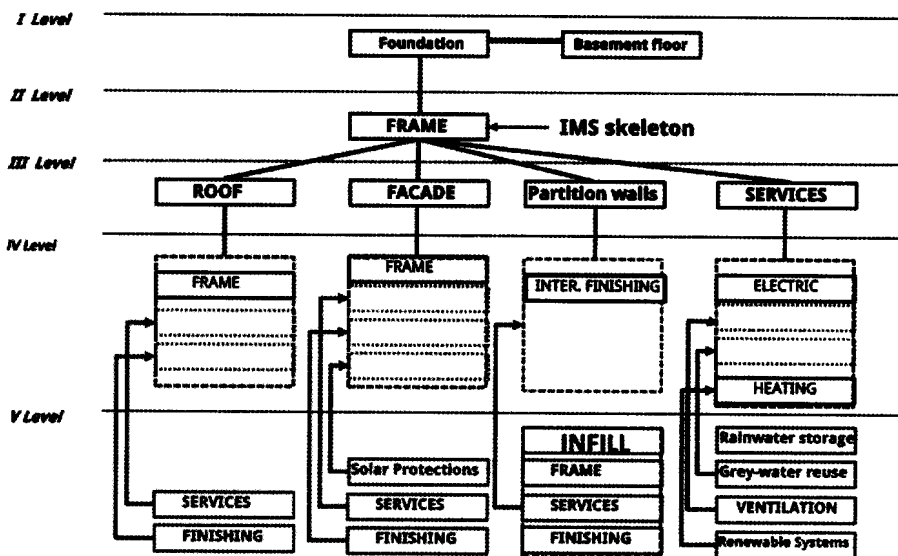

Figure 1 : Structural decomposition according to main building functions: Hierarchy Assembly.

Systematization of Components and Subsystems into Independent Technical and Functional Levels

Systems' configuration, which is flexible and demountable, is based on systematization of industrial components and subsystems according to independent functional and technical levels [5]. Two main aspects for systematization are independence and exchangeability of elements. Each technical level (all components, subsystems) has a life span that dictates its need for alteration or transformation. The more often a component (subsystem) needs to be replaced, the more accessible it ought to be [2]. Independent functional levels for components' systematization are

established according the principal housing functions: load-bearing, servicing, enclosing, interior partitioning. Every function in systems' building has corresponding technical level where different components and subsystems make physical connections. Technical building levels and conditions for the systems' and components' connections have a direct influence on building transformation capacity. In the figure 2, independent technical levels for different building functions are applied at the design stage to isolate building functions that have different service life. IMS load-bearing structure is independent level designed and constructed as flexible prestressed skeleton frame. Different systems and components for façade are independent from load-bearing structure which indicates its suitability for change.
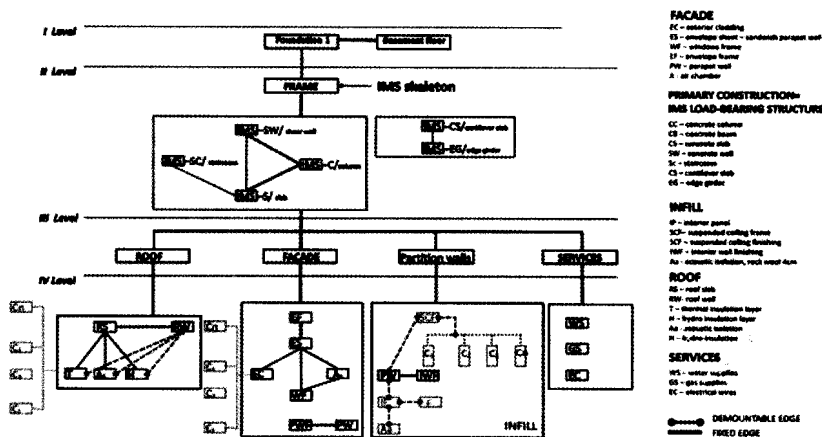

Figure 2 : Systematization of structural components in IMS systems' configuration.

The development of integrated but flexible systems' configuration will make use of industrial, flexible and demountable (IFD) components and subsystems into 'open' assemblies. The principal control for integrated systems lies in its possibility to be dismantled. Experience with flexible and demountable systems has shown that the real problems of sustainable construction are in the way elements are assembled into higher configuration levels. In the open systems' configurations long-life technical systems are first to be assembled independent from fast changing lower levels and its components (façade, interior wall). The type of joints and the interface geometry of the elements in connections play the main role to control assembly sequences in the systems' configuration model. Simple interface geometry of joint elements and demountable-dry joints are the main potential value of integrated massive structures. IFD structural connections will be used for planning new retrofitting scenarios of existing systems' configurations. Components that perform the same function are assembled into the assembly gropes – clusters (Figure 3). Figure3 highlights the principal systematization rules for 'open' systems' configuration. If P is a systems' configuration than A, B, C are its clusters: A-façade, B-services, C-load-bearing structure. The load-bearing cluster is composed of five independent subsystems and

components (c1, c2, c3, c4, c5) [8]. Systematization of components and subsystems into assemblies minimize the number of relations between elements within the structure and control the elements' position according to their life span. The process is based on specifying the group of elements (subsystems and components) – clusters that fulfils the same function. Type of connection between components – nodes in one cluster is responsible for changes and improvement of new performance values in the building layout. On the Figure 3 cluster C has five nodes (c1, c2, c3. c4. c5) and the relations between them depend of their interfaces and the type of connections. Node c1 is related only with node c3 which indicate its suitability for change. Different groups of elements can be assembled independently. Every assembly group is based on demountable dry-joints. Clusters that perform the same function belong to one hierarchical level. Figure 2 shows the two clusters of IMS load-bearing structure (cantilever cluster and main load-bearing cluster) are in the second hierarchical level.
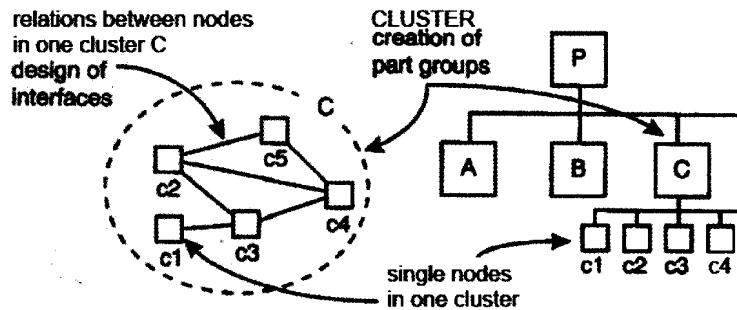

Figure 3 : Systematization of structural elements into assemblies (Tichem, 1997).

Specification of Demountable Configuration Model

Main aspects for decomposing of systems' configuration depend on analysis of the independent systems and components considering a possibility for: 1) functional decomposition, 2) controlled assembly sequences, 3) demountable-dry joints and simple interface geometry in connection.

Functional Decomposition

For understanding the real complexity of existing housing structures, the systems' configuration should be tested for decomposing of functions and components to understand the level of functional and technical dependency in the structure (systems' configuration). Two or more different functions mixed in one component, as in case with interior partition walls and its load-bearing function with embedded installations' pipes and ducts, represent the strongly dependent structural spots. From the Figure 2 we can conclude that IMS model is systems' configuration that allows integration of new systems and components at the level of façade, roof and new infill level in the

future retrofitting process. Existing IMS housing system are assembled so as to generate the possibility for integration of additional components for individual systems upgrading. On the third level, building façade will be analysed for integration of more energy efficient systems as well as the new retrofitting 'infill' for rehabilitation of dwelling units.

Open Hierarchy Assembly

Flexible and demountable systems' configurations systematized into hierarchy assemblies where adaptability at the component's level is possible according to compatibility issue and demountable-dry joints, is considered open systems' configuration. This internal hierarchy determines relations between different materials, components and subsystems and therefore the easiness or difficulty for the structural upgrading. Open hierarchy assembly takes into account that different parts of the structure have different lifetime and functional expectances. Systematization of this kind provides a precondition for the technical systems' alterations and changes. The IMS configuration (Figure 2) is defined by a number of different functional levels (foundations-Level I, load-bearing system- Level II, enclosing, partitioning, common services- Level III) where the dependency condition between technical systems and components is analysed and especially considered in the level IV. In IMS systems' hierarchy independent systems has one element that act as the base element for making connection with other subsystems in the hierarchy. For the façade cluster on the IV level e.g., the element such as window frame is the base element for all other parts of the window assembly: windows' wings, shadings, rails, and is connected with façade wall that makes connections with load-bearing structure. Such systematization of building structure through base elements and their connecting parts stands for the better control of the configuration, the use of exchangeable parts of the system, and total disassembly at the end of the building service life. Open hierarchy allows for the system to be extended with additional components and subsystems with improved autonomy and supports the future upgrading of different technical levels (Figure 2).

Demountable and Simple Connections

In order to evaluate the building structure as the open systems' configuration, two types of relations have to be considered: one between subsystems-clusters and components-nodes, and one within clusters. The components' interface in connection and the type of connection are the principal conditions for the systems' disassembly. Having in mind the level of functional, structural and physical domain in the structural configuration this research supports the development of the new integrated and intelligent solutions according to systematic approach based on simple and demountable dry joints. Bolted dry joints are used for the connections between façade panels and load-bearing structure in IMS housing building system. Figure 5 describes different types of relations between elements in IMS systems' configuration according to graph model.

Definition of the Configuration Graph Model

Graph model (Figure 4) is developed to describe the building structure by elements (components, group of components, assemblies) as a diagram of relations in systems' configuration model. Its application is twofold: i) Analysis of massive structure configuration as a mixed systems' configuration in order to investigate, describe and set up a configuration based on industrialized and 'cast in place' components viewed as a complex artefact of mixed functions and connections; ii) Development of integrated, flexible and demountable (IFD) systems' configuration for new building structures based on functional decomposition, controlled hierarchy sequences and demountable-dry joints.

Figure 4 : (a) Graph Model of Elements: Node, Edge, Cluster, and System; (b) Graph Model of Elements in IMS systems' configuration.

Figure 4a presents a graph model and describes its basic elements:
- a, b, c, d, e, f, are nodes – elements – components, is equivalent to a column of the load-bearing structure, partition wall, or water pipe.
- A, B, C, D is cluster – assemblies of elements (components or subsystems) and is equivalent to load-bearing structure (concrete skeleton composed of beams, columns, hollow core slabs).
- Edges are different types of connections-relations between different elements in the structural configuration model (Figure 4a). They will have the mayor importance in evaluation of dependency conditions in existing massive structures and will be taken into consideration for development of the new retrofitting strategies of the systems' configuration.

Conclusion

Massive structure is the complex artefact of industrialized components and systems, prefabricated elements made 'in situ' and / or in factory defined as a systems' configuration model. According to graph model description different types of connection has been established (Figure 4) and will be analysed to evaluate the dependency conditions between different parts in the configuration model. The relations between various elements are defined by elements' interface geometry and type of joint. Analysis of a massive structure through relations between various systems and components will highlight dependences between elements and detect the flexible structural spots to be used for future development of rehabilitation scenarios. Simple relations between nodes and clusters and detachable connections allow disassembly of the systems' configuration.

Evidently, every fixed connection between cluster and node (Figure 4b) is a non-desired edge in the structural model configuration. The cluster belongs to a higher level in the configuration hierarchy and the node, as a single element, is at the lower level that should change more rapidly. Any fixed connection between elements that are placed in different hierarchical levels is a non-desired edge. Fixed connection between two components from different levels is a problem when making changes can end up with a major demolitions and waste disposal. Finally, different housing buildings will have different rehabilitations scenarios according to dependency conditions between its structural elements analysed and established by systems' configuration graph model.

References

1. Stewart, B. – How Buildings Learn: What Happens after They're Built, Viking Press, New York, 1994.

2. Elma, D. – Transformable Building Structures: Design for Disassembly as a Way to Introduce Sustainable Engineering to a Building Design and Construction, Cedris M&CC, Delft, 2006.

3. John, N.H. – Variations: The Systematic Design of Supports, Laboratory of Architecture and Planning, M.I.T., Cambridge Mass., USA, 1976.

4. Stephen, K.; James, T. – Refabricating Architecture: How Manufacturing Methodologies Are Poised to Transform Building Construction, McGraw Hill, New York, 2004.

5. Ype, C.; Jeremy, B. – Capacity to Change, Index, Technische Universiteit, Delft, OBOM 1990.

6. Stephan, K.; Jonathan, T. – Residential Open Building, Ill., E & FN Spon, London and New York, 2000, ISBN 0-419-23830.

7. Frank, D.; Jeremy, M. – Design for Change: the Architecture of DEGW, Birkhauser, 1998.

8. Jelena, N. – Development of Industrialized, Flexible and Demountable Multifamily Buildings: IFD Collective Housing, Proceedings of 7th International Conference on Innovation in Architecture, Engineering AEC, São Paulo, Brazil, 15-17 August, 2012.

9. Jelena, N. – Retrofitting and Re-life of Massive Housing Structure: Case Study of New Belgrade Modern Residential Heritage, Proceedings of CIB2012, 18th International Conference on Open Building, Beijing, November 2012.