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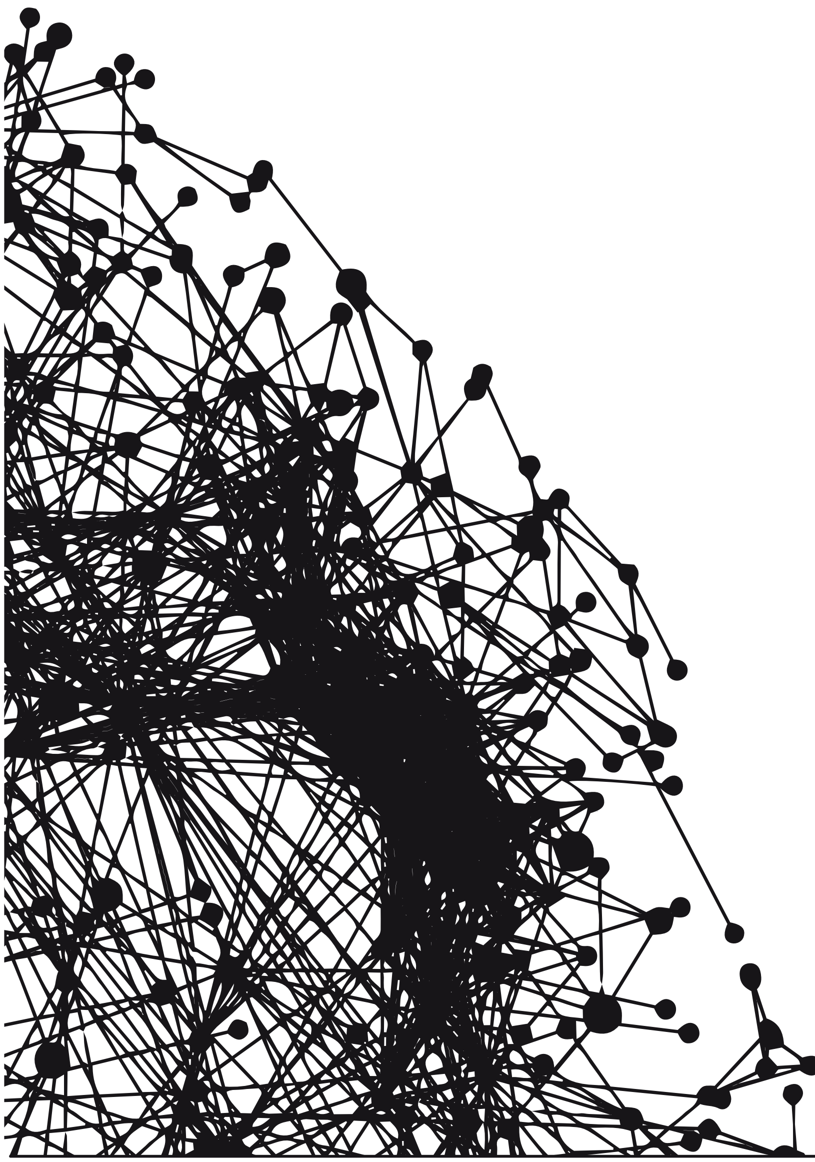

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CONTENTS

PART I: URBANISM

Urban planning and technologies

Urban design and technologies

Innovative materials, systems and technology

Cultural patterns, Architecture and technologies

TECHNOLOGICAL AND ENVIRONMENTAL ASPECTS OF RAPID HOUSING CONSTRUCTION

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Abstract

Rapid construction is a contemporary issue in building practice, related, but not restricted to Modern Methods of Construction (MMC), and similar production philosophies. While rapid construction is a worldwide applied principle of constructions of various typologies, this paper explores options of its application in Serbian housing practice since housing construction is still prevailing in the overall construction activity. Also, there is a significant historic background in domestic practice of prefabricated construction systems which was omnipresent in housing sector after World War II, giving remarkable results, both in number of constructed dwellings and their architectural quality. Although this practice existed throughout following decades, it was restricted to social and refugee settlements, and thus it did not re-establish itself as dominant in domestic circumstances, partially because it did not evolve in accordance with contemporary requirements. Most of all, contemporary paradigm of sustainability requires a new approach towards this practice, stressing the correlation between applied technologies and its environmental aspects, but also its social and economic values. These aspects define rapid housing construction in terms of applied constructive systems and materials, organization of building, issues of pollution such as waste, noise and dust, and pollution generated by material production and transport. This paper presents a study of contemporary practice of rapid housing construction with definitions of its technological and environmental aspects and perspectives of its application in domestic conditions.

Keywords: rapid housing construction, building technologies, environmental aspects

Introduction

Rapid construction is defined as: "... a concept to enhance the efficiency of construction process flow and to ensure the successes of project delivery in a chronicle time of contract by time reduction." (Yahya and Mohamad, 2010) The theory of rapid construction derived from the theory of lean manufacturing (pioneered by Toyota), especially its application in terms of construction management by several authors (Koskela, Ballard and Howell, Strickland and Kirkendall, Lecitia). As such, lean production is defined as: "...managing and improving the construction process to profitably deliver what the customer needs by eliminating waste in the construction flow..." (Yahya and Mohamad, 2011) Focusing on time as the most important type of waste generated in flow activities is narrowing the issues of lean production theories on specifics of construction processes, and the main characteristics of rapid construction. Seen in this way, Modern methods of construction (MMC) are the best example of rapid construction. Modern methods of construction (MMC) are defined as those which provide an efficient product management process to provide more products of better quality in less time. (BURA, 2005) It has been defined in various ways: pre-fabrication, off-site production and off-site manufacturing (OSM). However, the term is increasingly used instead of OSM, although it has much broader meaning, because not all MMC are OSM, while all OSM are MMC. But waste in construction is not limited only to time, but also to: quality costs, lack of constructability, poor materials management, excess consumption of materials on site, working time used for non-value adding activities on site and lack of safety (Koskela, 1993). There is a new relation between waste as a production issue and as a contemporary environmental issue, especially in construction industry, where it becomes the new paradigm of rapid construction.

Although MMC are widely applicable in various building types besides housing, they require a critical mass in production that needs to be achieved in terms of generating economies of scale. (BURA, 2005) Due to the current domestic conditions, where demand for affordable housing solutions still exceeds demands for other building types, in this paper we have focused on possible applications of rapid construction technologies in housing construction. Although worldwide "pre-fab" and system-build approaches have somewhat negative connotation, in terms of design, aesthetics and character, this should not be the case in Serbia, since domestic practice of prefabricated construction systems which was omnipresent in housing sector after World War II, gave remarkable results, both in number of constructed dwellings and their architectural quality, as presented in the paper. This is a positive starting point in the issue of consumer confidence for further development of these construction technologies.

We have overviewed several technologies of rapid construction together with their environmental issues regarding waste and selected those which are appropriate for application and development in domestic conditions.

Issues of Rapid Construction

There are various models of construction that fall under the definition of rapid construction. Although the most common is associating various pre-fabrication systems to rapid construction, it is not its exclusive manifestation, especially if we accept the broader philosophy behind rapid construction, similar to lean production theories. As construction is not every production resulting in a building, nor it is an industry, but a process (Bartelsen, 2004), then various models of building technologies could be seen as manifestations of rapid construction, if they fulfil the basic principle of lean manufacturing: maximize the value and minimize the waste. Terms of *value* and *waste* require a constant redefinition, according to contemporary paradigms, the actual one being sustainability. In these terms, environmental issues related to these different technologies largely define the new value set. We tried to relate various building technologies that fall under definition of rapid technologies to its key environmental aspects.

Traditional building technologies

Besides models of prefabrication, as obvious representatives of rapid construction, we also included some traditional building technologies that remain present for decades, and which gain new development momentum thanks to the contemporary environmental building movement. These traditional models are listed in Table 1, together with some of their environmental issues for consideration. Traditional systems are divided into two categories as massive and frame systems. Massive systems (masonry constructions, wooden and rammed earth structures) are usually, but not exclusively, being used for family dwellings today with constantly improving techniques of building and implementing contemporary building materials into traditional building technologies. Massive wood and frame wood systems are still in use, with their building technologies not evolving as fast as other traditional building systems (most of all masonry and rammed earth). Steel and concrete frame systems have a wide application, thanks to the relatively simple building technology, available worldwide, which has improved in time.

All of the traditional building technologies, applied according to the regional characteristics, have exceptional environmental characteristics, which influenced a lot in the worldwide revival of their application. This is mostly based on application of natural materials which fulfil most of the criteria for selection of building materials through the life cycle phases (Jovanović Popović, Kosanović, 2009) since they are locally available, have favourable characteristics related to human health issues, have a large reuse potential, and are easily crafted used local knowledge, encouraging local economies.

Some environmental issues of traditional systems are related to waste generation during construction on site, since there is usually no control over the construction process and waste generation, which can be managed appropriately. However, for example, traditionally mixed concrete on site generates less waste then pre-cast concrete which is ordered for large constructions. This only stresses the importance of implementation of project management into all types of construction, irrelevant to the scale of the project and technology applied.

Table 8: Correlations between technological and environmental aspects of traditional rapid construction models

TECHNOLOGICAL ASPECT			ENVIRONMENTAL ASPECT
TRADITIONAL	**MASSIVE SYSTEMS**		
	MASONRY (BRICK, STONE)	building with single elements, innovated building techniques, still in use	possibility of reuse, natural materials, low embodied energy, good thermal characteristic
	WOOD	massive wooden wall structures (traditional log cabins), non innovated building techniques	material waste, natural materials, embodied energy due to transport, thermal characteristics, fire, insect and dump protection
	RAMMED EARTH	still in use, innovated building techniques and materials	possibility of reuse, natural materials, low embodied energy, good thermal characteristic
	FRAME SYSTEMS		
	CONCRETE	improved traditional building techniques for cast-in-situ reinforced concrete, slabs, columns, beams, etc.	low material waste, issues of thermal characteristic, recycling potential
	STEEL	improved traditional building techniques on site, columns, girders, trusses, plates, etc.	material waste, recycling potential of elements, fire and dump protection
	WOOD	improved traditional building techniques on site, beams, columns, diagonal braces, rafters, etc.	material waste, embodied energy, recycling potential of elements, fire, insect and dump protection

Prefabricated building technologies

Prefabricated building systems are divided into frame and panel systems and further classified based on the main structural material used. They have several common environmental characteristics such as low material waste during construction, due to the industrialized process of production. Building elements produced in such way are assembled on the construction site, which eliminates waste generation activities. Key environmental issue thus becomes issue of transport of elements to the construction site, which encourages local economies to develop production lines nearby the construction site.

One of the key environmental issues in prefabricated systems is recycling of prefabricated construction elements. Frame systems elements could be recycled easier (single material element structure), while panel system elements have difficulties (complex element structures, multi material elements) during recycling process. Steel and wood systems (frame, panel) have special issues regarding requirements for fire and dump protection (steel, wood) and insects (wood).

Except listed models of rapid construction, other systems like cellular system, or some hybrid systems of construction are also present today. Cellular prefabricated systems are not listed in Table 2, since their application is usually combined with another building system. These systems are commonly in use for some building elements or partitions (technical rooms, toilets, bathrooms). Most of cellular systems have concrete or steel as basics materials, and each of them have own principles of construction and application.

Table 2: Correlations between technological and environmental aspects of prefabricated rapid construction models

TECHNOLOGICAL ASPECT			ENVIRONMENTAL ASPECT
PREFABRICATED	**FRAME SYSTEMS**		
	CONCRETE	improved building techniques, precast, prestressed, beams, columns, slabs, industrial production	waste and recycling issues
	STEEL	improved techniques of producing columns, girders, trusses, industrial production	low material waste, possibilities for recycling, fire protection
	WOOD	improved building techniques, glulam, massive elements, etc., industrial production	low material waste, possibilities for recycling, fire, insect and dump protection
	PANEL SYSTEMS		
	CONCRETE	composite precast systems, improved technology of industrial production and application	low material waste, complex recycling, good thermal characteristics
	STEEL	composite steel frame panel structure, improved technology of industrial production, application and materialization	low material waste, complex recycling, good thermal characteristics, fire and dump protection
	WOOD	composite wood frame panel structure, improved technology of industrial production, application and materialization	low material waste, possibilities for recycling, good thermal characteristics, fire, insect and dump protection

Lessons from domestic prefabrication

During the 1950s in Yugoslavia, groups of architects, civil engineers, urban planners and other engineers had to design and build a large number of dwellings in short time period, most of them grouped into new settlements, like New Belgrade. In this period of post-war construction industrialized building production and accompanying modular design principles were largely in use. This turning point in our building industry requested a new design methodology. Prefabricated design affected four areas of design:

- traditional building of dwellings since it could not be adjusted to industrial prefabrication and serial production,
- designing complete prefabricated systems and their elements,
- using prefabricated elements which could be found on market, and
- urban planning for those types of building systems (Trbojević, 1966a).

As a result of mentioned methodologies and engineering capabilities of that time several basic prefabricated systems were developed from 1950s up to 1980s. IMS system was the most widespread system in Yugoslavia (also was present in Cuba, Hungary, USSR, China, Angola, Egypt and Ethiopia). This presstresed and reinforced concrete system was designed as an experimental system by civil engineer Branko Žeželj. It is a prefabricated system formed from columns, slabs and precast concrete walls with structural purpose (Trbojević, 1966b). This system had a successful application in dwellings construction due to flexibility and compatibility with modular design. Also, many construction companies accepted this and some other systems and contributed to this new methodology of design processes for mass building production in 1960s and 1970s. Other basic system was Panel system which was created in two construction companies (KMG “Trudbenik”, GP “Neimar”). KMG “Trudbenik” system was formed from precast concrete panels which were vertically banded with precast concrete slabs (Jevđović, 1973). This system could be produced both in industrial and on-site conditions (Veselinović, 1973). GP “Neimar” designed hollow-core concrete wall panels and slabs. Other construction companies developed their own systems which were modifications of two basic systems (frame and panel systems). Many buildings and settlements were built up in an improved traditional building technology, with new materials, modern formworks, modern mechanization and prefabricated or semi-prefabricated elements.

During 1960s nearly 100000 flats were built up per year in whole Yugoslavia (Trbojević, 1966a). In 1963 several construction companies (GP “Rad”, KMG “Trudbenik”, GP “Napred”, OGP “7. juli”, GP “Neimar”, GP “Novi Beograd”, GP “Ratko Mitrović” and Insitut for material testing of SR Serbia) founded business association “Inpros” (Business Association of producers of industrial production of dwellings) for design, production of prefabricated elements, construction and landscaping (INPROS, 1969). This association successfully built up whole settlements throughout country due to its own factories for producing prefabricated elements. Only in Belgrade were two factories, Beograd I and Beograd II (Kubik, 1967). This production increased in 1970s and 1980s, with continuous work on improvement of those prefabricated systems.

New urban planning practice was also developed and plans for settlements were subordinated by the use of prefabrication and its technological processes of construction and schemes of use of mechanization. Described prefabricated and industrialized building construction gave numerous and often high quality results in our housing production, some of its highlights shown in Figure 1. However, exactly because of these exceptional architectural qualities, these buildings are complicated to retrofit and upgrade, since they no longer meet numerous environmental and housing comfort standards.

Figure 30: Highlights of domestic prefabrication

CONCLUSIONS - Possibilities for application of contemporary rapid construction models in Serbia

Following the intensive post-war construction, last decades are marked by a significant drop of construction activity, and its quality, due to the lack of organization on all levels of management. Applied building technology is mainly traditional masonry and concrete frame, slightly improved. Supply of secondary elements, such as insulations, finishing's and installations is diverse, but uneven in quality.

As shown in era of domestic prefabrication, construction companies have a large role in organizing their capacities and offering solutions to the market. In this way not only whole prefabricated systems can be offered, but also elements for traditional construction models which are compatible and thus easier to implement. Companies which produce precast concrete still exist but are specialized for industrial building and large span elements. With cooperation between producers of various elements (structure, insulation, finishing) and development of products which correspond to the contemporary functional, environmental and aesthetic demands, solutions that significantly ease and cheaper housing construction can be offered to the market .

Harmonized production of various compatible building elements offers a chance for significant reduction of waste by standardisation and high precision in production, and energy, by smart allocation of production facilities which could eliminate need for excess transport. Construction waste like noise and dust can be reduced by transition to more industrialized means of production and assembly on construction site. In this way principles of rapid construction can be applied to a variety of housing construction models. Also, regarding architectural quality of contemporary solutions, with application of new technologies and computerized production, design options are limitless, in terms of shape, format and number of elements, which is inspiring and provides numerous possibilities for exploration and development of new methods of construction.

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