Acta Technica *62* No. 2B/2017, 619–630

Application of the steel structure model based on modular coordination in optimization design of residential system in China[1]

Zhang Jinge[2]

Abstract. In order to promote the development of housing industry from extensive to intensive, and to realize the formation and perfection of industrialized construction system, in this paper, the current situation of serious lack of application research of modular design in residential building of steel structure in our country was put forward. On the basis of explaining the characteristics of steel structure residence, the design process, design method and selection of basic modulus were expounded. Then the modular location of steel structure residence was carried out, the positioning method was based on the installation way of the enclosure system, and the coordination of the outer protection system and the main structure was taken as the principle. The final research results show that the steel structure house can minimize the number of non-standard components and the number of installation nodes, and can increase the level of industrialization construction.

Key words. Modular coordination, steel structure residential building, systematic design.

1. Introduction

With the high PM2.5 and the intensification of Urban Haze, the quality of the living environment and the sustainable development of society have become the focus of attention. The real estate industry has begun to explore new patterns of development. It is a consensus that the building should be covered with a "green coat". Building a green and low carbon city has become the main theme of the times, and creating a scientific and healthy housing has also become a new trend in the development of the real estate industry. In the 12th Five-Year "planning" development goals, it is easy to see that energy-saving and green buildings have become

[1]This work was supported by the Research on Protection of Traditional Rural Culture and Development of Beautiful Countryside. Research on Nanyang "Painter Village" Intangible Culture's Protection and Countryside Development (2017-ZZJH-384, Education Department of Henan).

[2]School of Arts and Design, Nanyang Normal University, Nanyang, Henan, China, 473061

the development trend of China's residential industry. Therefore, in recent years, the relevant departments of the state have issued a series of guidance documents and norms on steel structure residential buildings to promote the development of China's steel residential buildings. The level of industrial production is the key to comprehensive evaluation of steel structure residential buildings, this is because industrialisation housing is standardized based on modularization. Industrialisation is constructed through standardization, and industrialization is strengthened through industrialisation. Standardization is the basis of industrial production. Modular design and standardization are the primary tasks of the establishment of steel structure housing system and its industrialization.

2. State of the art

The practice of steel structure housing system began in 1980s. For example, the Exhibition Hotel, built in 1987, adopted a steel structure system, with seven main buildings, surrounded by 3 layers of conjoined houses. And the steel used in the building mainly came from Canada, welding of square steel column and H type steel beam [1]. In November 1994, China completely built the first steel structure house entirely by itself in Beicai, Shanghai, which was the test type steel structure residential system of 8 layers. At present, the domestic steel structure system is mostly used in high-rise residential buildings, and with the continuous development of technology, the practice of steel residential structure is increasing year by year. Residential buildings with steel structure residence system have the advantages of flexible layout, green energy saving, good seismic performance and short construction period [2]. However, at present, the construction period of most of the steel residential buildings is no less than that of other residential buildings. This is mainly because that in the component of enclosure structure, the industrialized production of industrial products and the assembly characteristics of the construction site has not been realized. The selection of materials for the component of enclosure structure is limited, the rate of finished components is low, and the connection structure is imperfect [3]. Through the engineering practice, the experience of the scheme design, structure, equipment and technology of the steel structure house has been effectively accumulated, summarized as three points: the advantages of the steel structure are exploited, and the structure selection is more freedom. Different from the previous residential limitations of the "small bay layout", many cases adopt the "layout of large spaces". In order to realize the standardization of building components, the design of residence plane and space form is simple and regular, and the architectural details are less changed. In the course of the design of steel structure residence design, although there is a standardized design of structural parts, there is no systematic design method, and only the traditional design methods are used to consider the standardization of building structures and components [4].

3. Methodology

Building modulus is a unified value-added unit, which is used to harmonize building scales, so as to achieve large-scale production of industrialization, and to make the construction parts and components of different materials, different forms and different manufacturing methods with certain versatility and interchangeability [5]. Building modulus is also the basis for scale coordination of architectural design, building construction, building materials and products, building equipment, building components and other departments, the purpose of which is to make the fittings fit together and be interchangeable.

Modulus coordination is a standard scale system for the design, manufacture and installation of buildings and their components, formerly called modular systems. The purpose of building a modular coordination system for buildings is to realize the industrialization of building products and building components by means of standardization [6]. Requirements for modular coordination of buildings: the modulus series is used to adjust the dimensional relationship between the assembled monolithic building and the components (parts), and to optimize the dimensions and types of the building parts (parts); when the components (parts) are assembled, the sizes and positions of the parts (parts) can be clearly defined, so that the design, manufacture and installation can be easily matched with each other, so as to meet the requirements of the integrity, efficiency and economy of the assembly type architectural design.

The modular mesh is a modular space grid composed of three orthogonal coordinates with modulus dimensions, and the projection on the horizontal and vertical surfaces is called the modular mesh. The unit scale of a grid is a fundamental modulus or an enlarged modulus. Different amplification modulus can be used in three directions or the same direction of the grid [7].

The locating axis is the basis of the position of the component in the 3D mesh space. In the grid, each component is positioned in three directions by means of the boundary locating plane and the alignment line (or alignment line). The boundary location refers to that the boundary of the number of fingerprints is located in the component of the grid line, while the middle (or alignment line) refers to that the number of grid positioning line is located in the center line of the component (or partial center line) [8].

Construction Standardization refers to the establishment and implementation of relevant standards, specifications, rules and other procedures in construction [9]. The purpose of building standardization is to make rational use of raw materials, promote the versatility and interchangeability of structural parts, realize the industrialization of construction, and achieve the best economic results. Modularization is a form of standardization, for general purpose.

The steel structure residential system refers to the residential construction system whose main load-bearing component is steel, and the enclosure and partition members are new lightweight wall materials. The structural system of steel structure residence is the structural type composed of each load-bearing component with steel structural component as the main part [10]. The frame system is mainly com-

posed of beams and columns. The steel frame is generally made of concrete-filled steel tubular columns, and H steel is often used as steel frame columns. The high frequency dry type thin-wall steel beam, narrow flange shaped steel or other swing connecting I-beam are used as steel frame beam, and each type steel member has its own product series. The types of common dteels and their properties are listed in Table 1.

Table 1. Types of common steel and their sectional dimensions (in mm)

Type of steel	Section H steel (beam) (A×B)	Light channel steel (H×A×C)	Square steel tube (A×B)	Round steel tube (external diameter)
Common size	100–600×50–200	60–250×30–75×10–25	50–175×50–175	21.7–1219.2

The system has small dead weight, long vibration cycle and good seismic resistance, but its lateral displacement stiffness is small. Under the action of wind load and earthquake, the lateral displacement and the total lateral displacement cannot meet the requirements, and a variety of lateral resistance system must be set up. The lateral force resisting system is composed of connection support, shear wall and core tube of each frame [11]. Therefore, the structural system of steel residential structure is divided into the following, as shown in Table 2.

Table 2. Classification of steel structure residential structure system

Structural system name	Brief introduction
Pure steel frame system	Along the longitudinal and transverse sides of the house, the frame is used as the main component for weighing and resisting the side force
Steel frame (Center/ eccentric) support structure system	On the basis of the frame system of the building, a certain number of vertical supports are arranged in the longitudinal and transverse directions of the building
Steel frame shear wall structure system	In the frame structure, a certain shear wall is arranged, and the frame is combined with the shear wall
Steel frame core tube structure	A rigid or hinged steel frame is formed of a reinforced concrete core tube and an outer ring
Staggered truss steel structure system	It consists of columns, plane trusses and floor panels; the plane is rectangular or rectangular

The structural system, performance characteristics and the number of floors used in various steel residential structures are shown in Table 3. In the residential design, the selection of the steel structure residential system should follow the principles of safety, convenience and economy, and combine with the specific requirements of the function, modulus and maintenance of the house. At the same time, the use function of the house should be satisfied, so as to save investment.

Table 3. Comparison of structural performance of multi-story residential buildings

Resi-dential layers				Structural system name	Lateral resistance	Amount of steel used	Industrialized factory make-up	Structure construction difficulty and speed	Advantage	Disadvantages
Below 6				Steel frame	Bad	High	All frame system	Simple and fast	Simple structure rapid construction	Construction of sectional dimensions, uneconomical
	6–12			Bar truss	Very good	Low	Steel structure part	Relatively simple and fast	Good lateral resistance and large depth of bay	The truss has an influence on the graphic design of residential buildings
				Steel frame-bracing	Good	Preety low	All frame system	Relatively simple and relatively fast	Good lateral resistance and simple structure	The support has an influence on the opening of doors and windows and the adjustment of partition walls
		12–40		Steel frame-shear wall	Good	Low	Steel structure part	Relatively simple and relatively fast	Good lateral resistance and relatively simple structure	The shear wall has an influence on the opening of doors and windows and the adjustment of partition walls
			More than 40	Steel frame-core tube	Very good	Low	Steel structure part	Complex and slow	Good lateral resistance and good flexibility of the outer frame	Wet operation of some concrete

Through Table 3, it can be found that the structural system affects the graphic design of residential buildings. In order to avoid exposing the frame structure in the plane space, the wall and the beam column structure should be arranged on

the same line as much as possible. The steel frame column that is often used in residential system is about 6–7.5 m, and the construction area occupied by a single structural component should not be too large. As a whole, the cross section of the pure steel frame member is larger, which affects the plane space size. The frame in staggered frame will affect the plane arrangement. And the supporting elements in the steel frame bracing system can affect the layout of the facade doors and windows. In addition, in the frame shear wall, shear wall position will affect the position and arrangement of the partition door. The arrangement of the bracing system of the frame core tube is flexible and free from structural constraints, but there will be some wet work on site, the construction is more complex, and construction speed is slow. Therefore, in the design of steel residential structure, the structural system should be chosen according to the specific conditions.

Traditional residential design is the design process from a small proportion of macro architectural layout to a large proportion of technical details. However, the systematic design should coordinate the construction, the structure, the equipment, the construction and the production of the factory, and the goal is to produce a unique design process of the building system [12]. The design process is applicable to a large class of buildings. Before the specific architectural design, according to the characteristics of the building itself, technical issues should be given priority and systematized, so as to apply to the architectural series design in the system. As opposed to the traditional design process, the design process is called "reverse design process", and the design flow chart of the system house is shown in Fig. 1.

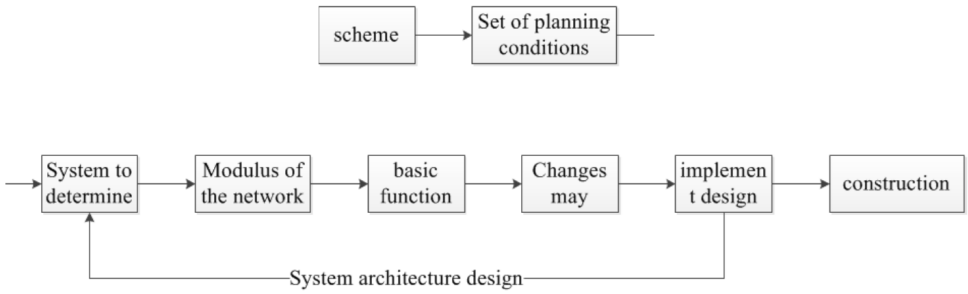

Fig. 1. Design flow chart of system house

Industrialized residential buildings are required to move from the site to the factory and from the extensive to the fine. Industrialized housing is a residential product with a manufacturing mode. Therefore, industrial residential design should combine the benefits of large-scale production and the market demand of small-scale production. Modularization is one of the techniques to fuse these two patterns. The highly standardized parts are simple in shape, and the standard function modules are rapidly configured by combining with the modular technology, so that a series of new products can be quickly obtained to meet the market demand, shorten the product life cycle, and accelerate the development process of the product. In other words, the internal diversity of performance is reduced, and the external diversity of production patterns is expanded [13]. Similarly, architectural modulus coordination can unify and simplify the specifications of building components, thus to make the

structure simpler, the construction more convenient, and to meet the diverse needs of building users. At the same time, the facade of the steel structure house needs the aesthetic effect of continuous rhythm and so on.

The modular mesh method is a design method based on geometry. A space grid is arranged in a size line, and the mesh gap is called modulus, and the design is carried out on the mesh. When the middle gap of the grid system is larger, the component specification is less, and the flexibility of the assembly is smaller. The smaller the middle gap of the grid system is, the more the component specifications are, and the stronger the flexibility of the combination is [14]. 100 mm is widely used as the fundamental modulus M in the world, and the division modulus and amplification modulus are developed on the basis of the fundamental modulus. The main application areas of modular modulus are: structural joints, product specifications, building materials, building cracks, and tolerances of building products. Enlarged modulus is mainly used for building branch spacing, span and height dimensions, and the range of its sequence directly affects the degree of simplification of the control dimension. Different types of building use different expansion modulus, and at present our country has stipulated different amplitude. The modular grid method is one of the most basic systematic design methods, because modulus is the basic unit of measurement for systematic architecture. The specifications, sizes (except thickness or sectional dimension) of the main components of the system shall be as much as possible to meet the design modulus or enlarged modulus. Moreover, the structural members of the modular grid can give full play to the structural properties of a balanced extension of a steel structure plane. The module network can be divided into building modulus network and structure modulus network. The building modular network is mainly used for the arrangement of function space and space combination, which can mark the net outline of the space, reflect the thickness of the wall, and facilitate the arrangement of the equipment and the design of the decoration. The structural modulus network is the basis of the structural component combination, which can indicate the axis of the column and the wall, so that the selection of the structural parameters and the rationality of the structural arrangement should be taken into account. The main parameters of the structure are the formulation of the production program and the modular setting of the housing factory. And the rationality of structural arrangement refers to the size and layout of the component, which is the basis of architectural design [15]. The grid of the main structure is different from that of the building space, but they should be consistent with each other. For example, when the space division function and the structure bearing function are the same, the building modulus network and the structural modulus network can replace each other. When the two are inconsistent, two different modular network systems are needed.

4. Result analysis and discussion

In the process of investigation, the plane of some steel structures in our country is drawn up. It can be found that the central location method is adopted in the residential part of steel structure in our country at present, and the basic moduli

are mostly 3M and 6M. An arrangement of modulus networks for a modular steel house is shown in Figs. 2–5.

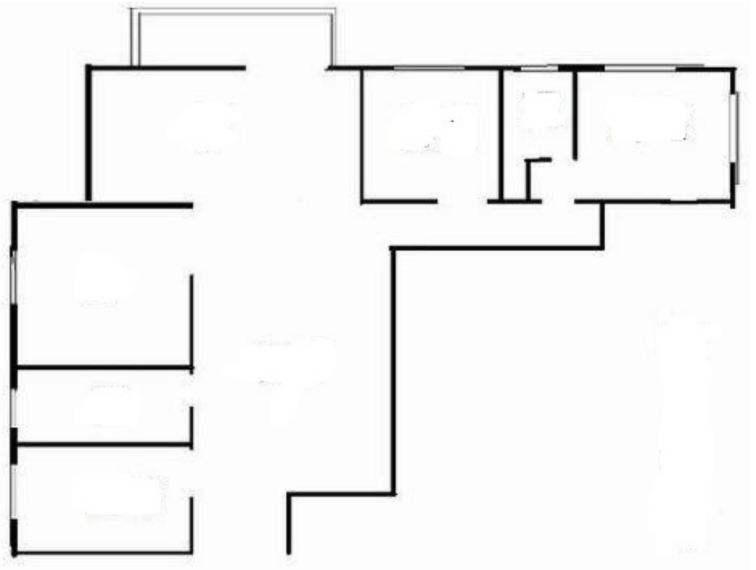

Fig. 2. Building 3 (apartment type), Jin Chen apartment, Beijing

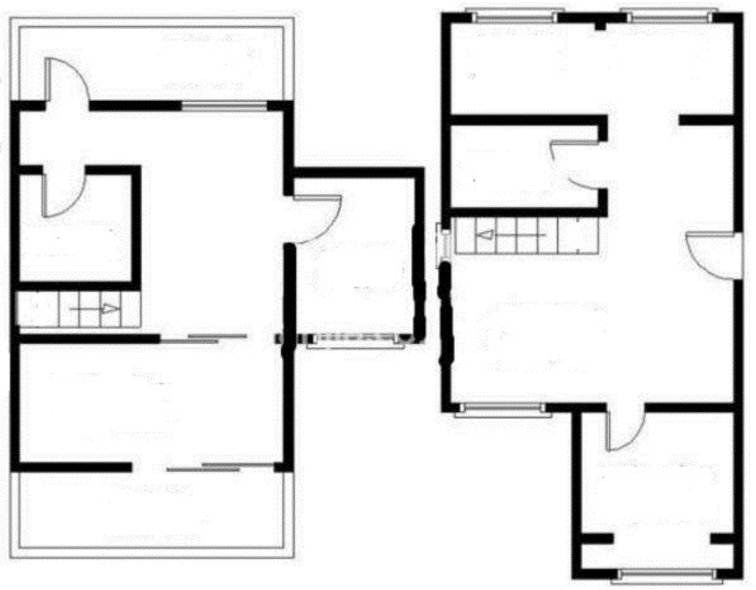

Fig. 3. Yizhuang youth apartment (drive)

Through Figs. 2–3, it can be found that in the current steel residential building, corridor style and unit type are designed by case 6M basic module, especially in the

unit type. In the investigation, there is no application of 6M basic design modulus in point house. Therefore, an existing case is selected to locate and transform it and the plan before and after the transformation is shown in Figs. 4–5.

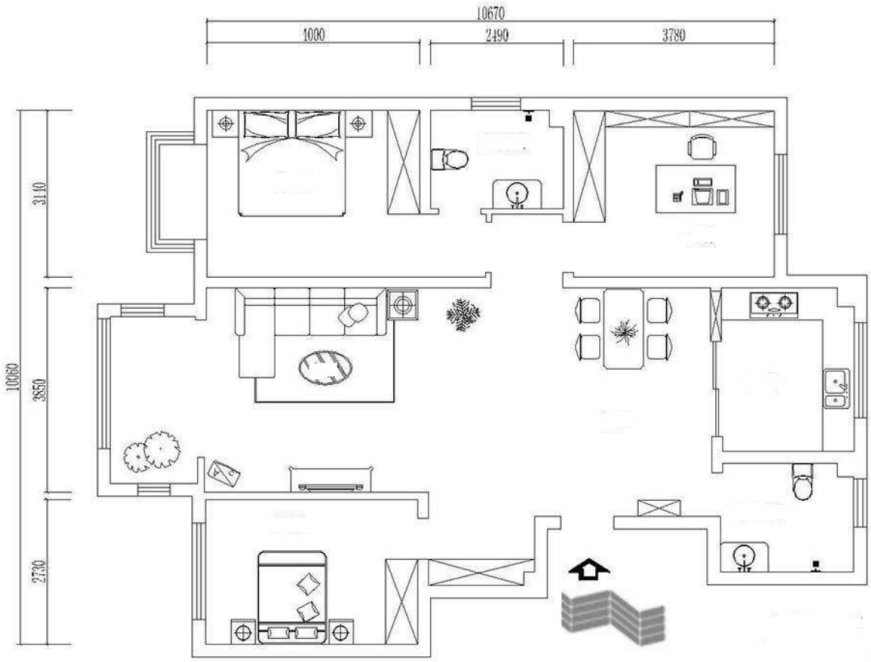

Fig. 4. The standard house of No. 1 building of Laiwu Iron and steel garden

Through the comparison of Figs. 4–5, it can be found that the function space of the plane changes little after using the basic design modulus of 6M, and can still meet the application requirements. Therefore, the design of 6M can also be used in our country's steel house.

There are different positioning methods in horizontal direction of steel structure residence. In order to ensure the interchangeability of parts and positions, and meet the requirements of functions, in actual project design, different positioning methods or hybrid positioning methods can be adopted to achieve economic and effective results. In view of the embedded exterior retaining component and the plug-in type outer enclosure component, the modulus coordination can be carried out by means of the net distance modulus method, or the positioning mode of combining the center line of structural column beam with modulus mesh. For the specific situation, the vertical direction can be coordinated by means of the linear high speed module or the high layer modulus.

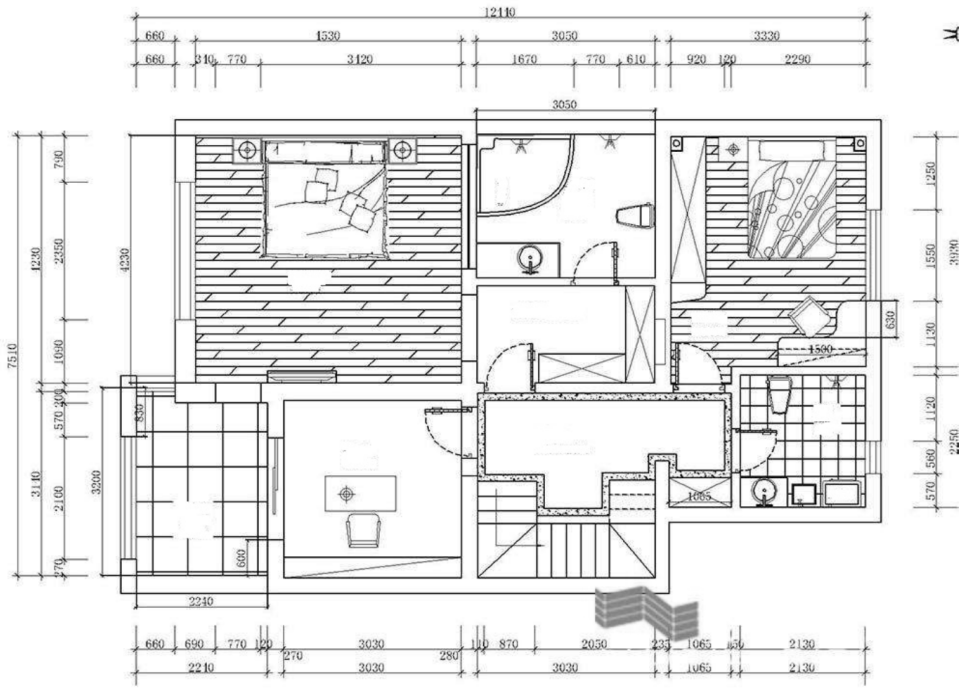

Fig. 5. Location of flat 6M of No. 19 Building of Sakura garden in Laiwu Iron

5. Conclusion

In order to study the application of the steel structure model based on modulus coordination in the optimization design of housing system in our country, in this paper, the system design was mainly analyzed, and the development process, system structure, design process and design method were studied. And system design method was the core of this paper. Through the previous research, the system design method was summed up. Through the research, some conclusions were drawn as follows: there are two main methods for the design of steel structure residence in our country: the modular grid method and the basic combination method. The modular grid method is the most basic system design method, whose purpose is to reduce the use of nonstandard components. There are two main parts of the research: the determination of basic modulus and location method. Moreover, there are three kinds of modulus positioning methods: central line positioning method, interface positioning method and fixed distance method. Central location method is a single structural system positioning method, and the interface location method and the fixed distance localization method are all aimed at the envelope system positioning method. The basic combination method is another method of system design, which is mainly used to solve the contradiction between standardized design and diversified requirements. Thus, in the future research, scholars can study how

to design the basic unit modules according to the modulus of the basic combination design.

References

[1] Q. L. Zhang, G. W. Feng, Y. Q. Zhang, B. X. Zhu: *Syntheses, structures, and luminescence properties of anion-controlled heterometal modular coordination polymers based on a metalloligand*. RSC Advances *4* (2014), No. 22, 11384–11392.

[2] E. Hofman, H. Voordijk, J. Halman: *Matching supply networks to a modular product architecture in the house-building industry*. Building Research & Information *37* (2009), No. 1, 31–42.

[3] L. March: *Rudolph M. Schindler: Space reference frame, modular coordination and the "Row"*. Nexus Network Journal *5* (2003), No. 2, 51–64.

[4] C. de Marchis, M. Schmid, D. Bibbo, I. Bernabucci, S. Conforto: *Inter-individual variability of forces and modular muscle coordination in cycling: A study on untrained subjects*. Human Movement Science *32* (2013), No. 6, 1480–1494.

[5] M. H. Filby, J. W. Steed: *A modular approach to organic, coordination complex and polymer based podand hosts for anions*. Coordination Chemistry Reviews *250* (2006), Nos. 23–24, 3200–3218.

[6] P. D. Jovančić, D. Ignjatović, M. Tanasijević, T. Maneski: *Load-bearing steel structure diagnostics on bucket wheel excavator, for the purpose of failure prevention*. Engineering Failure Analysis *18* (2011), No. 4, 1203–1211.

[7] M. K. Kuzman, J. Hrovatin, P. Grošelj: *Comparison of various types of residential building structures*. Građevinar *63* (2011), No. 9, 869–874.

[8] F. Fu, J. Sun, C. Pasquire: *Carbon emission assessment for steel structure based on lean construction process*. Journal of Intelligent & Robotic Systems *79* (2015), Nos. 3–4, 401–416.

[9] M. K. Kuzman, P. Grošelj: *Wood as a construction material: Comparison of different construction types for residential building using the analytic hierarchy process*. Wood Research *57* (2012), No. 4, 591–600.

[10] H. Takabatake, T. Nonaka: *Numerical study of Ashiyahama residential building damage in the Kobe Earthquake*. Earthquake Engineering & Structural Dynamics *30* (2001), No. TOC 6, 879–897.

[11] Y. Li, Z. Shen, X. Yao, R. Ma: *Experimental investigation and design method research on low-rise cold-formed thin-walled steel framing buildings*. Journal of Structural Engineering *139* (2013), No. 5, 818–836.

[12] D. Y. Seo, C. Koo, T. Hong: *A Lagrangian finite element model for estimating the heating and cooling demand of a residential building with a different envelope design*. Applied Energy *142* (2015), 66–79.

[13] J. Li, T. P. White, L. O'Faolain, A. Gomez-Iglesias, T. F. Krauss: *Systematic design of flat band slow light in photonic crystal waveguides*. Optics Express *16* (2008), No. 9, 6227–6232.

[14] A. I. Papadopoulos, M. Stijepovic, P. Linke: *On the systematic design and selection of optimal working fluids for Organic Rankine Cycles*. Applied Thermal Engineeringh *30* (2010), Nos. 6–7, 760–769.

[15] J. S. Jensen, O. Sigmund: *Systematic design of photonic crystal structures using topology optimization: Low-loss waveguide bends*. Applied Physics Letters *84* (2004), No. 12, 2022–2024.

Received September 12, 2017