ARCHITECTURE OF BUILDINGS AND STRUCTURES. CREATIVE CONCEPTIONS OF ARCHITECTURAL ACTIVITY

UDC 72.012

D. O. Fedchun[1]

A COMPARATIVE ANALYSIS OF THE METHODS OF GENERATIVE, PARAMETRIC AND INFORMATIONAL ARCHITECTURAL DESIGN

Far Eastern Federal University
Russia, Vladivostok
[1] *PhD student of the Dept. of Architectural Environment and Interior Design,*
tel.: (423) 243-34-72, e-mail: fedchun.do@dvfu.ru, monfed@bk.ru

Statement of the problem. The methods of informational, parametric and generalizing design in architecture are compared in order to suggest the technologies to be used in actual designing.
Results. Modern methodologies of architectural design are considered. Their comparison and search for perspective directions of the development of a generative design system of an architectural project are carried out.
Conclusions. This comparison revealed the most effective methods in informational and parametric design. The methods were found to introduce the data into the methodology of generative design and determine its future development.

Keywords: generative design, information designing, building information model (BIM), methodology of architectural design, parametric architecture.

Introduction. Development of an architectural project is based on choosing a technology and designing method. It is vital not only to how a project will be designed but also to its characteristics and how likely it is to be completed at all. Each method has its own features, advantages and disadvantages. In this paper we are proposing our own technology of developing a system of generative designing [15] and comparing it with other existing methods of information and parametric designing, further directions to be taken to improve the system based on comparing it with existing solutions are looked at. The objective of the paper is to identify the prospects and new ways of designing architectural projects [9] and to compare them with the methods of parametric and information designing (based on the technology *Building Information Model* (*BIM*) [15, 18].

1. General concept of generative systems. The concept "generative architecture" is as broad as it is popular, however, its correct definition is not to be found in the field of style but rather designing methodology it offers to architects. This method presents a shift in the role played by a designer from someone who is immediately involved in algorithmic designing systems that develop architectural projects based on the analysis of original data and operation of generative algorithms.

This process relies on designing algorithms that form the geometry of a future building using mathematical or physical dependencies of its elements between one another as well as analyzing a large dataset on a construction site, climate and construction features in this particular area [1]. This solution allows for a variety of different projects only by changing original designing data. Based on this concept, we came up with our very own system of generative designing for low-rise residential buildings [15].

The algorithm (Fig. 1) includes three major stages: collecting and analyzing original design data, designing an architectural project based on processing the information and documenting the results in the form of a set of sketches.

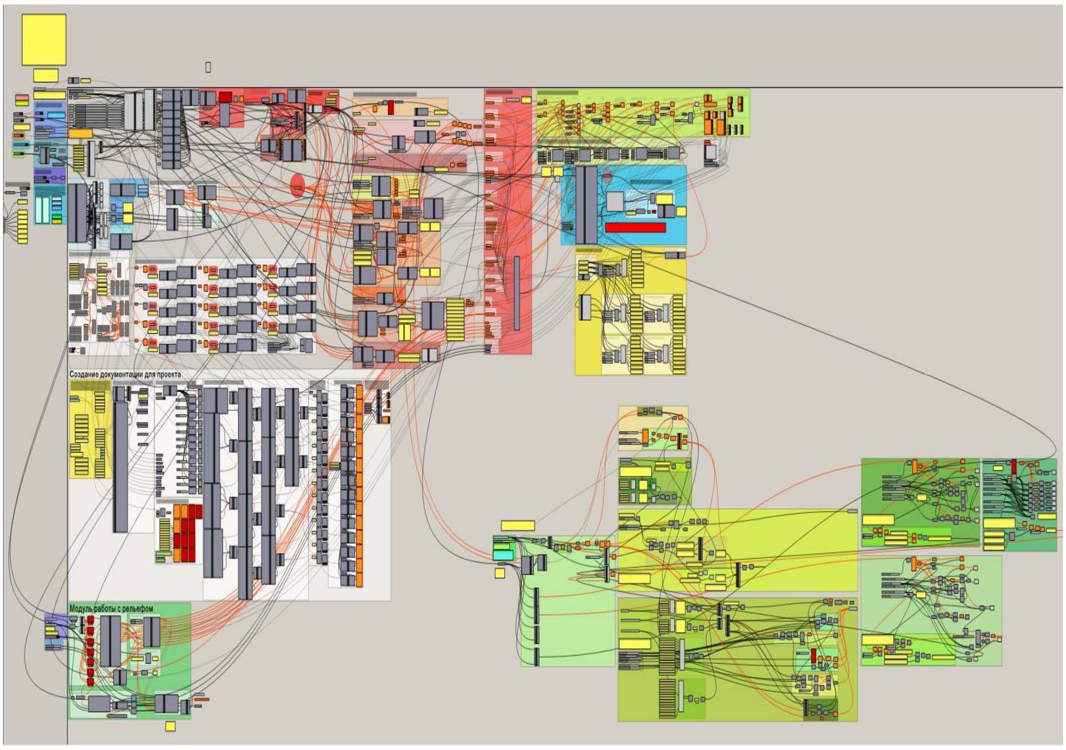

Fig. 1. Algorithm for the author's very own generative designing system for low-rise residential buildings

Let us look at the stages in more detail. 1. Working on the original data. One of the features of generative systems is maximum automation of collection of data necessary for starting a design followed by its further collection by means of an algorithm. In order to make this stage as automatic as possible, original data is constrained with a cadastral number of the area and choice of major facilities and their number in a future building. It is also possible to make use of topophotography of the area for more accurate results.

A cadastral number of an area allows one to identify the location of a designed object, automatically obtain information on the relief (if there is no topophotography), climate and insolation as well as buildings and structures in the vicinity.

Choice of facilities is constrained with a number of bedrooms and a set of extra premises (a library, a garage, a sauna, etc.). A combination of chosen facilities is analyzed by means of an algorithm and based on the resulting information, a list of future premises is designed. Based on the number of the chosen rooms, sizes of a location and its relief, there is a certain coefficient of the area of a building that the sizes of designed rooms as well as extra premises (closets for each bedroom, toilets, etc.) depend on. They get an extra set of certain characteristics including the following elements: a range of sizes, windows, doors and their type, necessary parameters of internal microclimate and a type of finishing materials.

2. An algorithm for developing architectural solutions. At this stage an algorithm creates a functional and planning scheme between the rooms, joins them into one planning solution that further volumetric and spatial elements of a building are based on.

The mechanism of designing a plan and architecture is directly influenced by the original data collected at the first stage. Using predetermined dependencies and conditions, all parts of a building are designed: foundations, internal and external walls, shuttering, roofing, etc.

Fig. 2. Architectural solution designed with a generative designing system

Designing each element of a building has to be based on well-informed decisions. E.g., each window opening, its position and sizes are defined by the characteristics of a room where it is, its orientation to the north, south, etc. and insolation requirements for facilities [4].

3. Documenting the obtained result. The last operation performed by the algorithm is creating project documentation for designed architectural solutions. There are two main operations at this stage of the algorithm:

1) designing and converting the information into textual and graphic format, forming sheet samples;

2) filling the samples with information and storing it as individual files.

As part of the first operation following the design of volumetric and spatial solutions of the task, certain sheet samples are created. At this stage of the project development, there is only “A Project Sketch” where the following set of sheets is created: a title page, a short explanation note, floor plans (the number varies and changes dynamically), facades of a building, two cuts and general view shots (Fig. 3).

As any of the original data changes, so do a volumetric and spatial solution and thus a resulting architectural project.

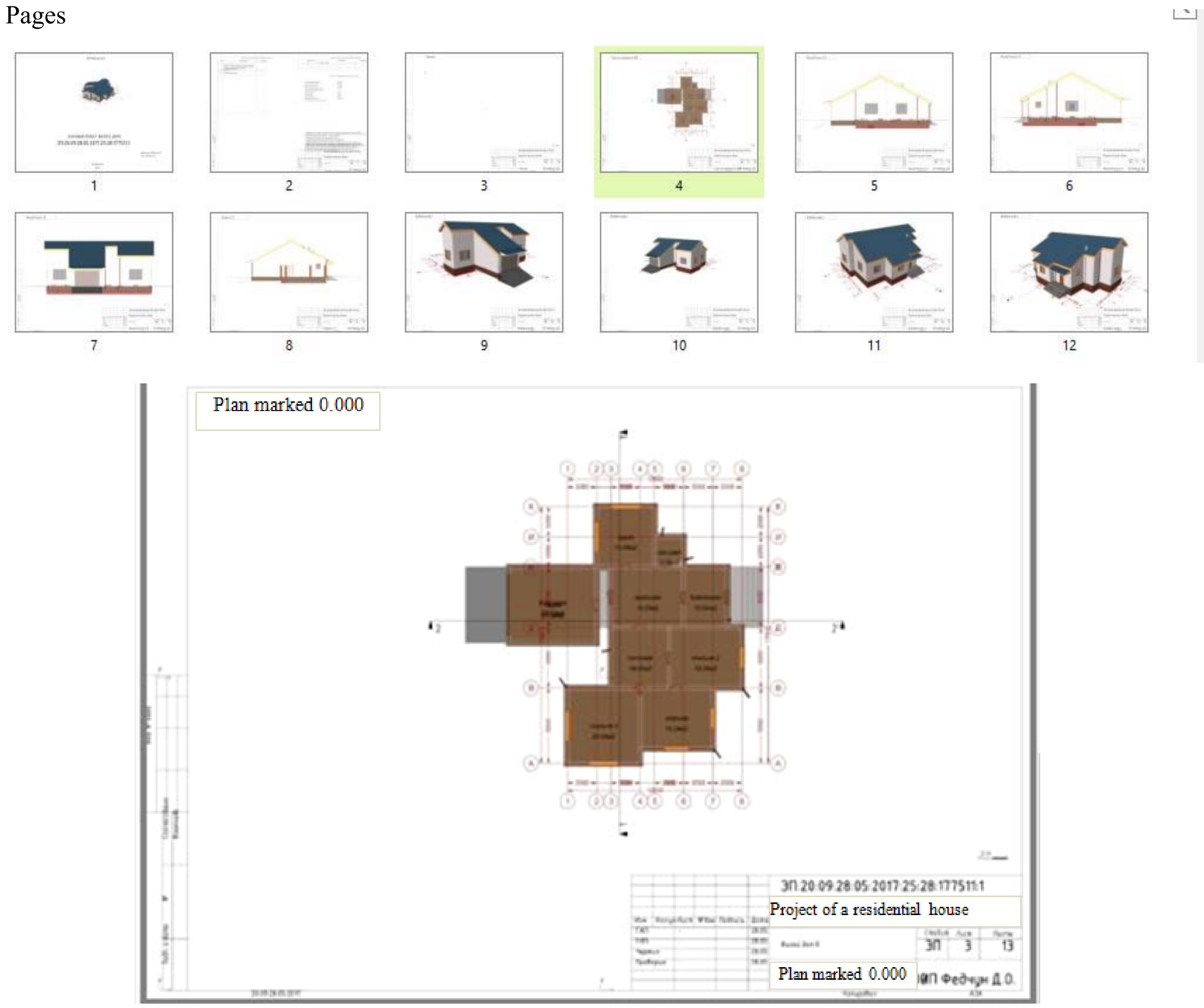

Fig. 3. Album of architectural sketches created by the algorithm

2. Comparison of the performance with original data for information, parametric and generative method of design. Collecting and analyzing original design data is an important stage in developing an architectural project as it is at this stage that a foundation for future project solutions is laid and its overall quality heavily depends on the information collected. Different designing methods prioritize data use differently. The use of geodata of designing areas is necessary for any designing method since demographic or sociological data in information designing (based on the *BIM* technology) often have a low priority and are thus not employed.

While developing a project by means of the information method, data can be classed into two categories: necessary ones (data on an area, technical designing task, etc.) that are integral to an architectural project and extra ones that can be made use of depending on a designer's qualification and expertise, time constraints and a degree of the development of particular design solutions (insolation data, climatology, analysis of surrounding construction work, transportation, etc.). The reason for this sort of information not being completely used is that collecting and analyzing this data manually is rather time-consuming.

The basis for the parametric approach to building design is collecting and analyzing maximum amount of different information that can further be used for designing project solutions based on it. Parametric designing involves collecting and processing a large amount of information on the specifics of a building and its individual interpretation by a designer (Fig. 4). Systems of collecting and structuring original data include automatic and manual methods. This information set encompasses the following databases: economic, social, demographic, political, topographical, climatic as well as other characteristics of a designing location, engineering and transport infrastructure, construction morphology [9, 11—12].

Collecting a dataset	Processing	Results
— Social data — Ethnography of a location — Political factors — Climatology — Engineering communications — Economic factors — Transport infrastructure — Environment analysis — Geodesic and geological data and some other characteristics	— Data analysis — Conceptual designing — Sketch designing — Working designing	— Complex of parametric models of the same object — Architectural and construction documentation of a building

Fig. 4. General scheme for the parametric designing method

For the generative designing method to perform well, it is necessary that there was a sufficient amount of original information used by the system. Data that can be collected as automatically as possible is given top priority. This allows a large amount of information to be used in designing, which enables a project to be obtained which considers a maximum number of possible factors that are challenging to use by means of traditional designing methods (Fig. 5).

The advantages of this designing method are a multiple reduction in designing times, growing detail and quality owing to automatic use of a maximum possible amount of data that can be added manually.

Collecting a dataset	Processing	Results
— Social data — Ethnography of a location — Political factors — Climatology — Engineering communications — Economic factors — Transport infrastructure — Environment analysis — Geodesic and geological data and some other characteristics	— Processing of the original data and designing an architectural solution by means of a generative designing system	— Architectural and construction documentation of a building

Fig. 5. General scheme of the generative designing method

By using a system of generative designing, we obtain a new approach to creating and justifying suggested project solutions stemming from a variety of social and economic, technical and other factors, connection with a location and historic characteristics. This allows automation of design and thus boosting the productivity of project solutions [8, 9].

3. Comparing the methods of forming volumetric and spatial solutions for the information, generative and parametric design. Information designing is currently one of the most common methods in architectural designing. It is due to the fact that this system of project development can be utilized through its entire span — from a sketch to construction documentation, equipment, operation and subsequent re-equipment or dismantling. An information model being designed includes all the data on architectural and construction solutions, economic and technical aspects of a building as well as interactions and dependencies (Fig. 6). A building in this designing model is viewed and designed as a single object with no divides between architectural and construction solutions and engineering systems [7].

A feature of this designing method is creating a shared information database where each element of a building has a set of major characteristics and extra stands. A change in the properties or size of one associated with another causes an automatic correction of the remaining elements, change of all the sketches as well as specifications and visualizations [12].

A flipside of the information designing method is a direct dependence of the design quality and experience of architects utilizing the technology. In order to take advantage of all the positive aspects of the information model, a long-term special training is required. This restriction prevents the technology from being fully exploited as there are no objects to be designed, which might lead to direct losses and other associated issues at the time of construction and operation.

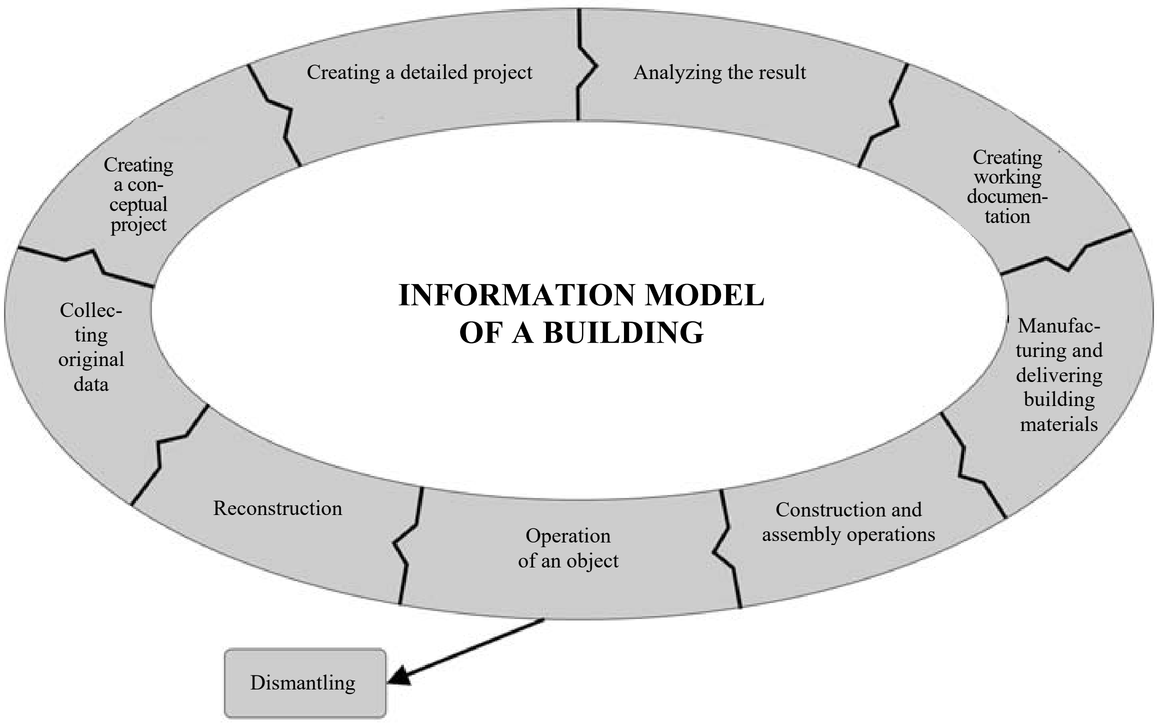

Fig. 6. General scheme of an information model

The parametric designing method employs another model of organizing design: it is based on combining different software and creating some segmented models that are further joined into one common file [16, 17]. For making changes to a project it is necessary to go back to the level of a model fragment. At different design stages various software packages are utilized: for three-dimensional modeling such as *Autodesk Maya* or *Autodesk 3DS Max*, at the stage of the development of a parametric model a project is transferred into *Grasshopper* or other similar visual programming products, then at the stage of designing documentation standard programs such as *Autodesk Autocad* or *Revit* are employed.

The most prominent feature of the method of parametric designing that sets it apart from information designing is that for handling each specific task a particular software is utilized and models are all joined together only to create a final-end project (see Fig. 4).

The generative designing method includes the most effective solutions from the information and parametric designing methods. The foundation of designing is creating a common algorithmized information model of a building. It includes scripts and algorithms that repeat the way a building is designed by an architect but do it automatically. A project is created according to the deductive principle: a general situation is investigated, location of a building and its relief, a general planning structure is designed which is used to create a volumetric and spatial solution of a building and as a result, project documentation is developed.

There are several ways of creating a planning structure: evolutional (mathematical) and physical [14, 15, 21]. The first one relies on a mathematical model that creates a population of solutions and using an analyses, it selects those that meet the specified criteria as much as possible [5]. The second method is to create a physical model of a building that is formed by means of physical effects of colliding, gravitation and repulsion of objects resulting in an overall structure of a building. In this example the second method is employed [18—21].

Creating a volumetric and spatial solution takes three main stages.

1. Analyzing the relief of an area and choosing the most optimal one as a building location. For that purpose, a toposurface is fragmented into segments according to its orientation to the north, south, etc (considering the distance to the objects surrounding the area, passageways and urban-planning constraints) and an extra analysis of its relief is conducted. The results of the analyses performed by means of an algorithm are a point of a future building location (Fig. 7).

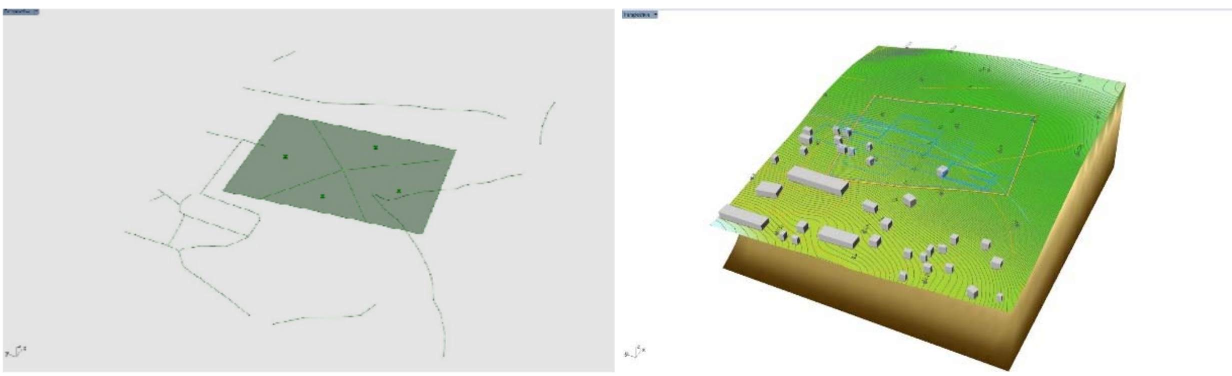

Fig. 7. Analysis of the relief of an area and choice of the most optimal one for a building location

2. Creating a planning solution. For that, a point is used that is found at the first stage. The algorithm forming the plans of a building uses two phases in its operation: creating a concep-

tual structure of a volumetric and spatial solution and a detailed plan. The first phase operates by means of two abstract primitives: lines and parallelepipeds. At the second one, walls, shuttering, windows, doors and other elements of the plan are designed.

For the first stage a general functional scheme of how the rooms are connected is created and their primitives are designed and joined into one common structure (Fig. 8).

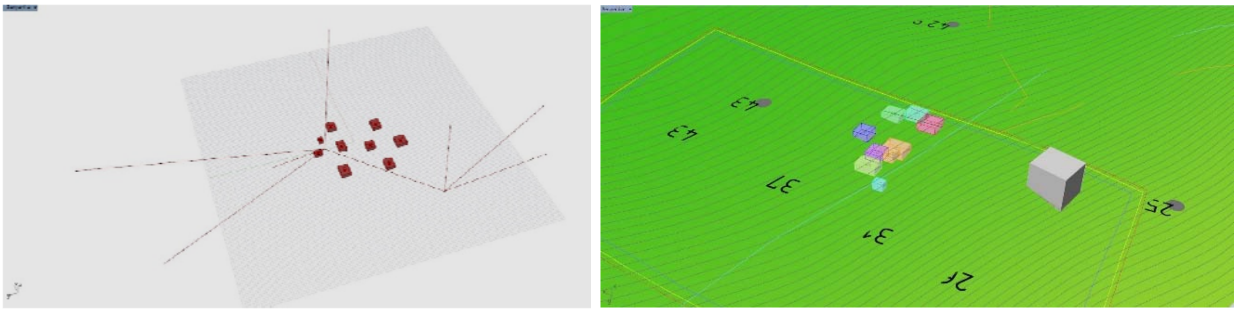

Fig. 8. Creating functional connections of the rooms and a common planning structure

The second phase is creating a volumetric and spatial solution for the resulting structure using the preliminarily specified criteria and conditions (Fig. 9).

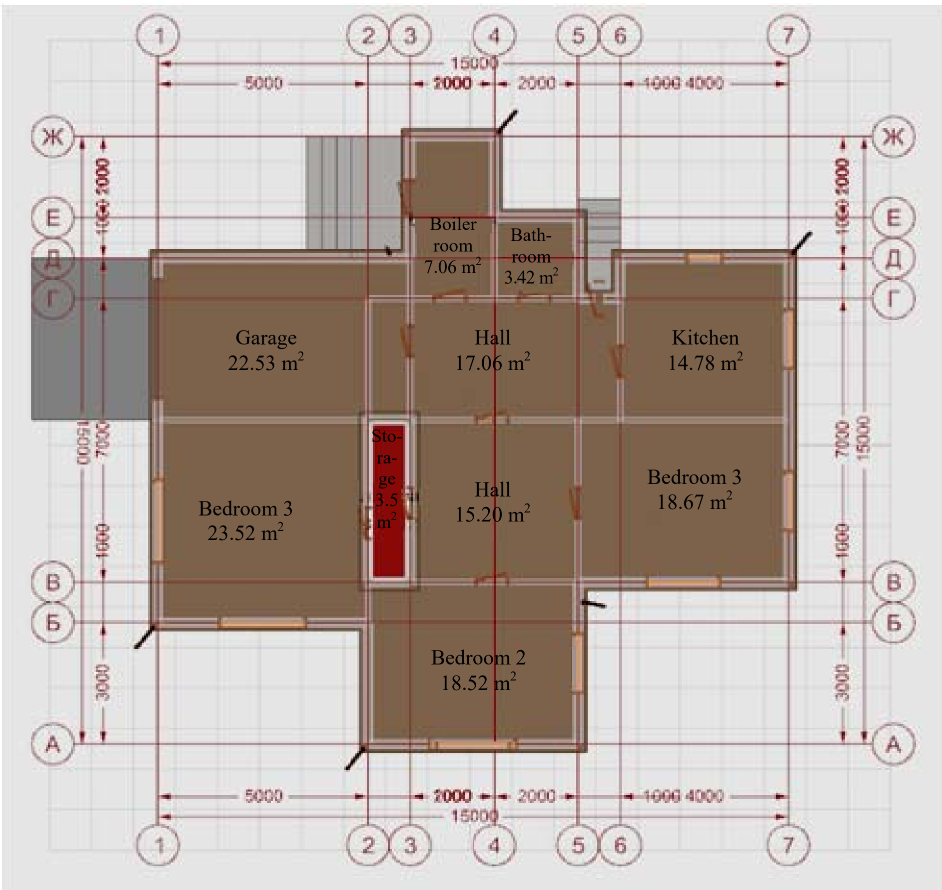

Fig. 9. Designing a volumetric and spatial solution using the resulting structure

3. Designing architectural and construction solutions. At this stage, the remainder of the elements of a building is designed: roofing, foundation, engineering systems, etc. Each element at this stage is modeled based on the system of the parameters and a set of formulas. E.g., a roofing system is formed by means of analyzing a planning structure, climatic factors and location of a building in the area (Fig. 10).

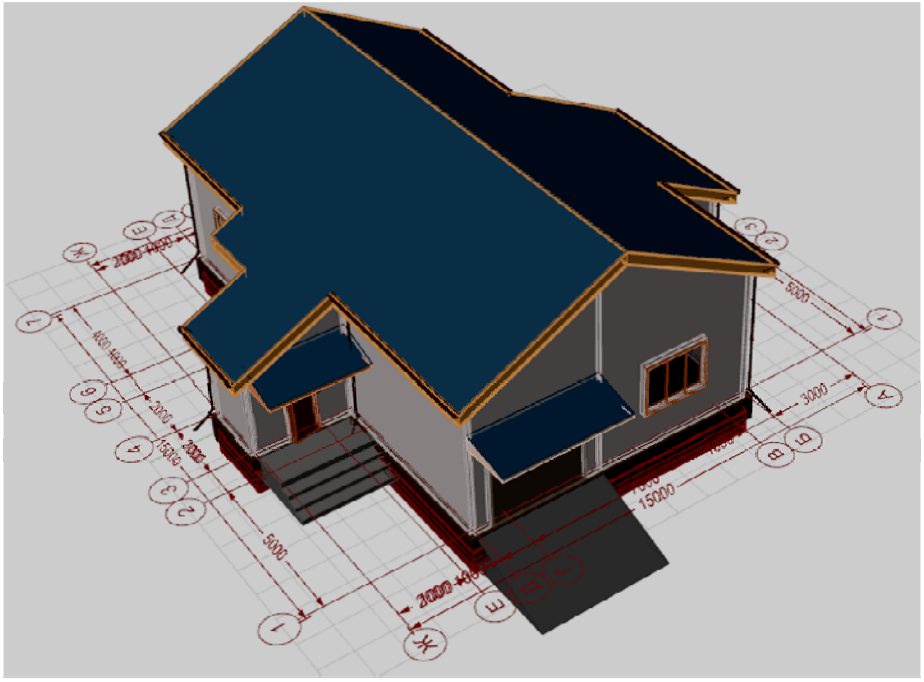

Fig. 10. Architectural solution designed by means of the algorithm

The method of generative designing allows an aesthetic model of a project to be created where rationality, mathematics and analysis of designing conditions underlie the exterior of a building. This property makes it different from information and parametric designing models where the exterior of a building is defined by an architect or a group of designers based on their personal tastes, expertise and skills. Using the generative methods, what an individual does is to specify a set of the parameters and a system of their use where an algorithm forms the aesthetics of a building and its characteristics depends on the amount of factors that affect the exterior of a designed object.

4. Comparison of economic aspects of parametric, information and generative designing methods. The designing stage in the total structure of construction costs accounts for less than 5 %, but the total economic losses caused by errors and mistakes made in the process of architectural designing can be significantly higher due to increasing estimated construction costs [3].

According to the data by the company *Autodesk* [6—7], a considerable proportion of Russia's construction companies would incur an almost 20 % rise in construction costs compared to the one estimated prior to the construction. Overall, an average difference between estimated and actual costs might be as high as 50 %.

The main cause is due to the discrepancies between building structures and engineering networks that inadvertently lead to costly corrections and longer construction times. One of the most common mistakes is that there are no technological gaps for engineering systems, erroneous calculations of the volume of work and amount of materials. Mistakes occur as a result of inconsistencies, no interactions between the architects, designers and engineers working on different parts of a project. The solutions they come up with might turn out to be inconsistent and contradictory. In practice, it is rather challenging to find this sort of mistakes in 2D sketches (Fig. 11).

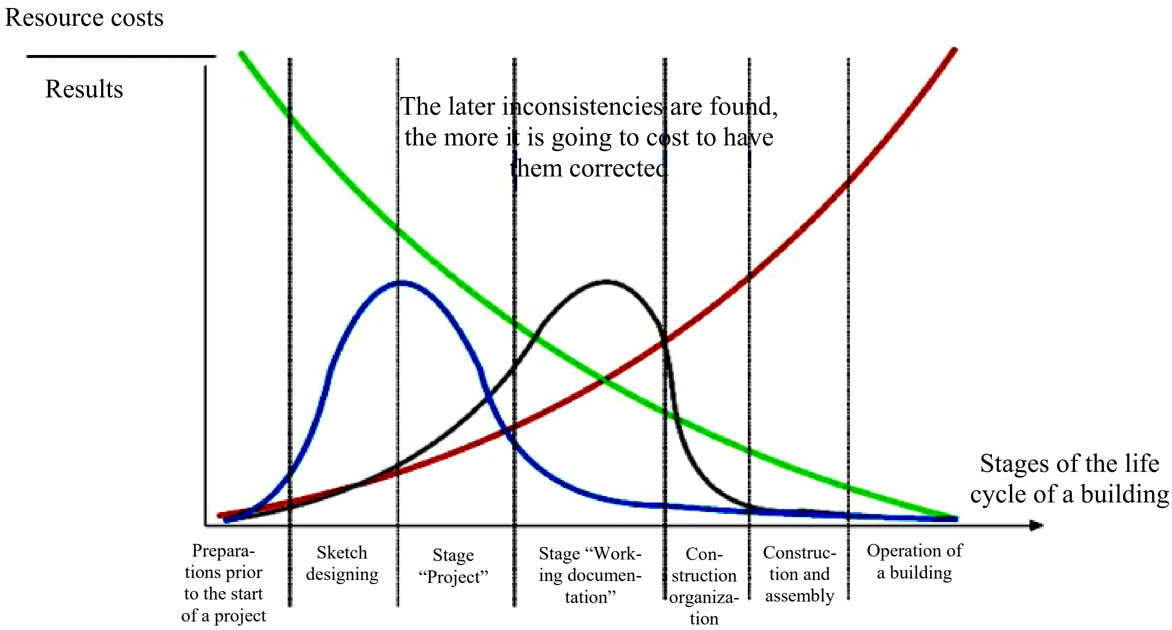

Fig. 11. Graph of resource costs and stages of a life cycle of a building: is a likelihood of changes; are costs of making changes; is an activity peak for traditional designing; is mistake detection in the process of information designing at different stages of a project

The advantage of the information designing method is a common model for all the specialists involved in a project and room for collaboration [2]. The technology allows the entire designing process, i.e. from the concept to working documentation, to be conducted in one file with constant control over detail and changes made by other specialists. This enables errors and mistakes to be identified at early stages, which considerably reduces their correction costs. Nevertheless this kind of organization of a model makes it more complicated to make use of non-traditional solutions due to unification and constraints of forming shapes for supporting a large number of specialists from a variety of fields.

The parametric method of designing relies on a project model that is created using specialized submodels [22]. This approach to organizing a model involves decomposition of a designed object into different subsystems given structural and functional connections and designing a common hierarchy between them. Decomposition of design leads to its representation as a set of more simple designing procedures at different levels of a hierarchy [13]. Each procedure employs its own software set to allow for a more detailed handling of a designed object and non-traditional solutions which are not constrained with a general model, which is the case for information designing.

Conclusions. Information and parametric designing methods are characterized by shared advantages and disadvantages. A positive point is that there can be as many specialists working on a project as necessary, which is organized and controlled by a single system. A downside is high costs for design organization which utilizes a whole variety of specialized software products as well as high requirements for the qualifications of specialists employing the above methods. The major economic effect of the use of these methods is a lower amount of mistakes and inconsistencies of solutions in working documentation due to a common model of a designed object, which allows financial construction costs to be reduced.

The method of organizing generative designing is based on another approach to models. It relies on development of a common system consisting of a set of algorithms [13] and utilizes another organizational structure for designing a project of a building. Designers work on creating system conditions and regulations to be further employed for architectural solutions. Then it is possible to develop building projects only by making changes to original data. By spending a large amount of time at the outset of a project, this organization of designing allows construction times for buildings of one category to be significantly reduced. For the author's very own generative designing system considered in the research paper it took a year of development and 10 minutes for each new iteration that leads to a new project. Further attempts at improving the system will be focused on the major algorithms, original data and quality of project solutions.

Comparing the methods of parametric, information and generative design methods was necessary for identifying the main directions and methods of developing a designed generative system. This indicated high prospects of creating a single information model of a building as part of designing as well as methods of collecting and analyzing original data in the process of parametric design. The obtained results in the form of connections and units, the identified advantages of a variety of methods should drive the development of a new direction in creating architectural projects, i.e. generative design.

References

1. Avdot'in L. N. *Primenenie vychislitel'noy tekhniki i modelirovaniya v arkhitekturnom proektirovanie* [Application of computer technology and modeling in architectural design]. Moscow, Stroyizdat Publ., 1978. 255 p.

2. Grakhov V. P., Mokhnachev S. A., Ishtryakov A. Kh. Razvitie sistem BIM-proektirovaniya kak element konkurentosposobnosti [Development of BIM design systems as an element of competitiveness]. *Sovremennye problemy nauki i obrazovaniya*, 2015, no. 1, pp. 580—587.

3. Dronov D. S., Kimetova N. R., Tkachenkova V. P. Problemy vnedreniya BIM-tekhnologiy v Rossii [Problems of BIM technology implementation in Russia]. *Sinergiya nauk*, 2017, no. 10, pp. 529—549.

4. Kazantsev P. A. *Osnovy ekologicheskoy arkhitektury. Uchebnoe proektirovanie energoeffektivnykh zdaniy. Teoriya i praktika energoeffektivnoy arkhitektury* [Fundamentals of environmental architecture. Educational design of energy-efficient buildings. Theory and practice of energy efficient architecture]. Germany, Lambert academic publishing, 2012. 205 p.

5. Krivenko A. A., Moor V. K., Gavrilov A. G. Generativnoe proektirovanie kak sredstvo formirovaniya arkhitekturnykh ob"ektov [Generative design as a means of formation of architectural objects]. *Arkhitektura i dizayn: istoriya, teoriya, innovatsii*, 2017, no. 2, pp. 203—206.

6. Malinovskiy M. E. BIM-reglament proektnoy organizatsii [BIM-regulations of the project organization]. *Al'manakh mirovoy nauki*, 2016, no. 7, pp. 123—124.

7. Mamaev A. E., Sharmanov V. V., Zolotova Yu. S., Svintsitskiy V. A., Gorodnyuk G. S. Prikladnoe primenenie BIM-modeli zdaniya dlya kontrolya investitsionno-stroitel'nogo proekta [The application of BIM model of a building for the control of investment construction project]. *Aktual'nye problemy gumanitarnykh i estestvennykh nauk*, 2016, no. 3, pp. 83—87.

8. Puchkov M. V. *Arkhitektura v epokhu informatsionnykh tekhnologiy* [Architecture in the information technology era]. Ekaterinburg, Arkhitekton Publ., 2006. 118 p.

9. Puchkov M. V., Butenko A. A. Parametricheskoe modelirovanie arkhitekturno-prostranstvennoy sredy goroda na osnove informatsionnykh tekhnologiy [Parametric modeling of architectural and spatial environment of the city on the basis of information technologies]. *Arkhitekton: izvestiya vuzov*, 2015, no. 49, pp. 23—28.

10. Rizaeva A. D. Generativnyy dizayn: programmirovanie, kak novyy instrument deyatel'nosti dizaynera [Generative design: programming as a new designer working tool]. *Mezhdunarodnyy studencheskiy nauchnyy forum RAE*, 2015, no. 7, pp. 41—47.

12. Stamenkovich M. Z. *Parametricheskie metody proektirovaniya* [Parametric design methods]. Moscow, Izd-vo MARKhI, 2016. 36 p.

13. Terlych S. V. Metodika avtomatizirovannogo parametricheskogo proektirovaniya konstruktsiy elementov zashivki pomeshcheniy dlya nesamokhodnykh plavuchikh sooruzheniy [Method of computer-aided parametric

design of constructions of elements of stitching of rooms for non-self-propelled floating constructions]. *Vestnik SevNTU. Mekhanika. Energetika. Ekologiya*, 2015, no. 88, pp. 52—55.

14. Khayman E. A. [Script in architecture. Architect as a Director-programmer]. *Materialy nauch. konf. "Vzaimovliyanie arkhitektury i kul'tury (Ikonnikovskie chteniya — 2008)"* [Proc. of scientific conference "The Interaction of architecture and culture" (Ikonnikovskiy reading — 2008)]. Moscow, 2008, pp. 60—68.

15. Fedchun D. O., Tlustyy R. E. Sistema generativnogo proektirovaniya [System is a generative design]. *Arkhitektura i dizayn: istoriya, teoriya, innovatsii*, 2016, no. 2, pp. 164—169.

16. Fedchun D. O., Tlustyy R. E. Evolyutsionnye metody sozdaniya planirovochnykh resheniy maloetazhnykh zhilykh zdaniy [Evolutionary methods of creating planning solutions for low-rise residential buildings]. *Arkhitektura i dizayn: istoriya, teoriya, innovatsii*, 2017, no. 2, pp. 238—241.

17. Cheon J., Hardy S., Hemsath T., eds. Parametricism (SPC): ACADIA Regional 2011. Conference Proceedings. Lincoln, DigitalCommons@University of Nebraska, 2011. 315 p. Available at: https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1021&context=arch_facultyschol.

18. Garber R., ed. Closing the Gap: Information Models in Contemporary Design practice (Architectural Design). London, Wiley, 2009, vol. 79, no. 2. 144 p.

19. Holland J. Genetic Algorithms. USA, First MIT Press, 1998. Available at: http://masters.donntu.org/2008/kita/dzhura/library/ref_7.htm.

20. Jacobi J. 4D BIM or Simulation-Based Modeling. Structure Magazine, 2011, April, pp. 17—18. Available at: //web.archive.org/web/20130612094235/http://www. structuremag.org:80/Archives/2011-4/C-InSights-Jacobi-April11.pdf.

21. Khabazi Z. Generative Algorithms Using Grasshopper. Bangalore, India, Morphogenesim, 2010. 179 p. Available at: https://ru.scribd.com/doc/49132581/Generative-Algorithms.

22. Schaffranek R., Vasku M. Space Syntax for Generative Design: on the Application of a New Tool. Proceedings of the Ninth International Space Syntax Symposium. Seoul, Sejong University, 2013. 12 p. Available at: http://www.academia. edu/9042735/SPACE_SYNTAX_FOR_GENERATIVE_DESIGN_On_the_application_of_a_new_tool.

23. Terzidis K. Algorithmic Architecture. Oxford, Architectural Press, 2006. 176 p.