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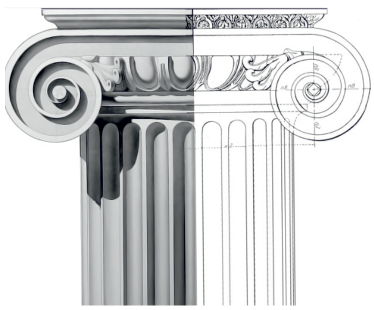

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Civil Engineering

7D BIM FOR SUSTAINABILITY ASSESSMENT IN DESIGN PROCESSES: A CASE STUDY OF DESIGN OF ALTERNATIVES IN SEVERE CLIMATE AND HEAVY USE CONDITIONS

Marta Andreani[1], Stefano Bertagni[2], Carlo Biagini[3], Filippo Mallo[4]

[1,2,3,4] University of Firenze
via della Mattonaia 8, Firenze, Italy

[3] Corresponding author: carlo.biagini@unifi.it

Abstract

Introduction: The emerging of energy and environmental thread has fostered a new cultural design approach to Sustainable Architecture that aims to conceive and implement buildings with a low environmental impact. In this context the role of Building Information Modelling (BIM), as a support tool for sustainable integrated design, acquires great relevance. The purpose of this study is to investigate BIM potential in both addressing preliminary design choices and supporting complex analysis during the advanced design phase, within the whole sustainable design process. A technological rail building is assumed as a case study: the Operation Control Centre for the new Oman Railway, whose preliminary project was elaborated by the Italian engineering society Italferr s.p.a. **Methods:** The BIM approach is used to identify possible problems and deficiencies in the preliminary project, which may represent a good basis for a next design improvements proposal. The next phase consists in investigating and experimenting BIM tools potential in supporting the Conceptual Design, by using Autodesk® Revit® and IES VE® software suites, for the modelling and the energy analysis of different conceptual design solutions. Once the optimal building shape is established, the study focuses on the evaluation of sustainability effects brought by the structural building component, in particular for what concerns its materials environmental impact. **Results and discussion**: The analysis of the preliminary project shows the potential of BIM in the control of many performance parameters of a building in the design phase, revealing all the design problems associated to the lack of an integral multi-disciplinary approach during the initial phases of the process. The possibility of looking into a series of solutions in a quick and in-depth manner permits an accurate assessment of the most adequate form for a building based on the place in which it is set, thus joining current technological design methods to traditional bio-climatic methods, reinstating the strong and inevitable link between site and building.

Keywords
7D BIM, sustainability, life cycle assessment, design of alternatives.

Introduction

With the growing emergence of environmental and energy-related issues and new requirements in terms of sustainability of built systems, a new cultural approach to the project has become necessary, aimed at the design and construction of Sustainable buildings, that is with a low environmental impact, combining practical criteria related to the “on time, within budget” requirements with social and environmental factors (Banuri, 2007; United Nations, 2016).

However, for the term Sustainability to assume a comprehensive meaning in architecture, it is necessary for architects and designers to use not only the analytic tools that are related to their discipline, but also tools for combining and synthesising, following a synergic logic which should guide the entire building and design process. It is thus clear in this context how Sustainable Architecture, identifying itself with a variety of disciplinary fields, all equally important for establishing the perfect balance between environment and built system, requires a multi-disciplinary and integrated approach to the project (Allione, 2008; Szokolay, 2004). The main objective of sustainable design is surely energy efficiency, the first factor that permits the reduction of the consumption of resources by the building and justifies successive choices in terms of materials and technological solutions which allow limiting as well the environmental impact during the construction and disposal phases of the building, always limited if confronted to the one determined by the period of usage (Fowler, 2006; Bertagni, 2016).

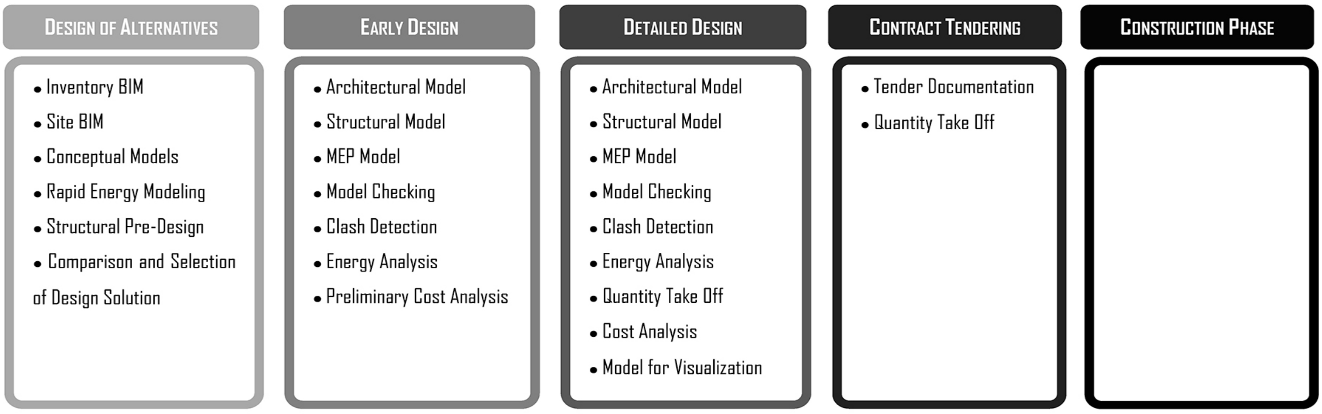

Figure 1. BIM design phases according to "Common BIM Requirement".

In order to consider all the energy fluxes in play, the most correct and sophisticated criterion envisages carrying out an LCA (Life Cycle Assessment) analysis on the building to assess the environmental impact of the building through an objective procedure, considering the energy and environmental loads regarding all the processes involved in the construction, usage and disposal phases of the building in question (Bank, 2011; Baldo, 2008).

Sustainability assessment methods can be configured as tools in support of design, assuming a different role during the various design phases. During an initial assessment phase regarding design alternatives, they can be used for defining the requirements of Sustainability and the determination of the aims regarding environmental performance in order to choose among a variety of design solutions; during the successive phases of definitive and executive design, these methods are defined as support tools for designers, helping them to obtain a clear perception of how the environmental performance of the building is influenced by design choices and how to intervene for optimising the cost/benefit ratio (Kensek, 2016; Berardi, 2012).

A solution for making a more expedite assessment is offered by BIM technology, which is capable of simplifying the optimised management of the data of the project, and permits in-depth energy analysis, also for the less advanced design phases, thus offering support for quicker and more efficient decision-making processes (Kota, 2014; Nguyen, 2010).

The role that BIM can play in offering support to sustainable and integrated design is different according to the various phases of the project considered. According to “Common BIM Requirements” (BuildingSMART Finland, 2012), it is possible to distinguish the typologies and contents of parametric models carried out in support of the 5 main phases (Figure 1): the initial phase of preparation of the various design alternatives (Design of Alternatives), in which the modelling of the existing situation is envisaged, as well as the realisation of various conceptual models on which to carry out expedite analyses with the exclusive purpose of comparison; further elements are a preliminary design phase (Early Design) (Aksamija, 2015; Stumpf, 2008) in which architectural, structural and installation schematic models are developed, and an additional, more advanced design phase (Detailed Design), which reaches a more in-depth degree of analysis in support of more precise assessments of the performance of the building. Finally, the parametric model can be used as a tool in support of the production of documents for competitions to tender and for the management of data regarding the building in its usage phase (Eastmam, 2011; Eadie, 2013).

Scope, Objectives and Methodology

In order to examine in detail the potential of parametric modelling and of the interoperability between BIM systems as tools for optimising projects in terms of sustainability, it was decided to trial them in a case study: the Operation Control Centre (OCC), of the new national railway line of the Sultanate of Oman (Figure 2). The project for the entire infrastructure, developed by the engineering company Italferr S.p.A., envisages the construction of 9 railway segments for the transport of goods and people (for a total length of 2135 km) that link the main urban centres of the country, crossing the desert from the North, on the border with the Arab Emirates, to the coastal regions in the South, on the border with Yemen.

The OCC houses the management centre for the entire railway and, as such, must contain all the functions and equipment necessary for the control and security of the railway traffic. The control rooms constitute the most relevant “human component” in an OCC, clearly counterpoised to the “technological component”, which includes the ever-present machinery; the former include all the equipment directly used by the operators, which consist mostly of integrated work stations, with monitors for visualising the segments and controlling traffic, and telecommunication devices that are essential for its coordination. In the machinery rooms, instead, are placed all the equipment in support of the activities of the operators (telecommunication cabinets, machinery for the automation of signalling and distancing systems, etc.) with the respective electricity supply units.

The contrast within the building between the two “components”, one human and the other technological, is manifested in both terms of mere function and in terms

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of requirements demanded from the built organism: the interior spaces, in fact, must be conceived so as to house a variety of activities, respecting the needs of both in terms of accessibility, distribution, environmental conditions (for the functioning of equipment and for the comfort of the operators), and seeking a perfect balance in what is called the Man-Machine Interface, from an environmental point of view, but also from that of ergonomics and functionality (Stanton, 2009). Consider the peculiar nature of the building, both in terms of its location and of its usage, it is particular interesting to apply on this case study the energy considerations regarding the interaction between the form, orientation and the local climate, from a perspective of the general optimisation of the performance.

Modelling and simulation

The whole intervention is structured according to the scheme proposed by "Common BIM Requirements" previously cited, from the Design of Alternatives phase to the last step in the design process, the Detailed Design. Various formal solutions are analysed, with the aim of identifying the one with the greatest energy efficiency, from which variations are developed in terms of the structural constructive system (to be compared through LCA analysis), with the objective of including, among the impact indicators under examination, also those relative to construction materials. At the end of the comparison, the model potentially more sustainable will be taken to the successive phases of Early and Detailed Design, in which the interferences between disciplinary models are controlled and united into a single object, after which the executive reports are drafted (Eastman, 2011).

Design of Alternatives. In the framework of the first phase of Design of Alternatives, BIM modelling in Revit® in LOD 200 of the preliminary project, carried out by the company Italferr s.p.a., consists in the definition of general wall elements and in the layout of the sun screen louvers for protection from direct solar radiation.

The "rooms" defined inside the BIM model were exported, through the conversion into the format gbXML, into the energy analysis software IES VE®, which is capable of extrapolating information from it related to the location of the building and associating them automatically with the relative climatic data. The Building Energy Model (BEM) obtained is used for carrying out analysis of the efficiency of the external sun screen louvers, on the level of natural lighting of the spaces, and more generally, on the aspects relative to solar radiation and on its influence on the building itself, considering the important role that it plays in the geographic context in question.

Once the phase of analysis of the preliminary project has concluded, a verification of the efficiency of the BIM tools is carried out in the phase of comparison of the various design solutions, generating several

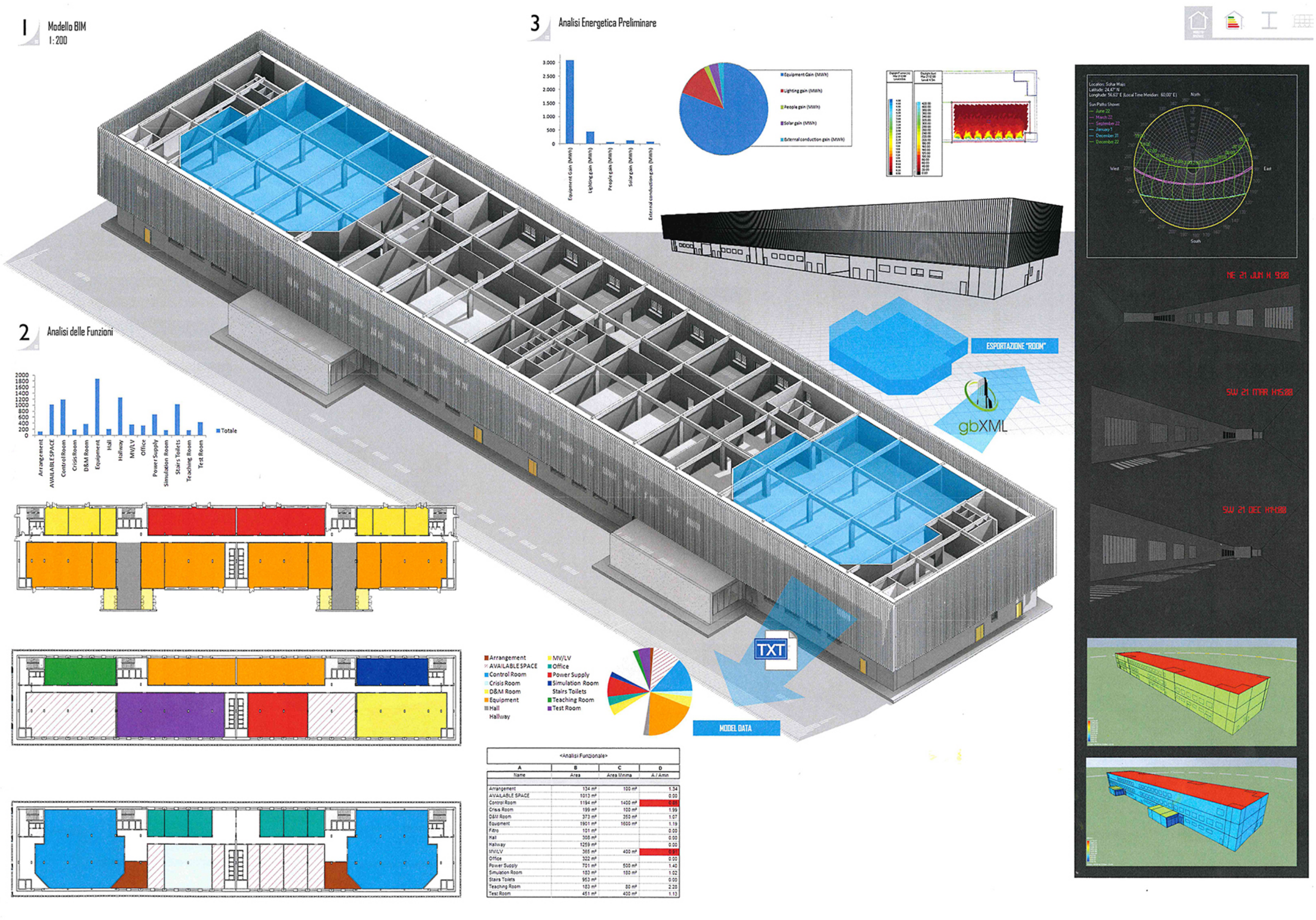

Figure 2. Modelling in LOD 200 from Italferr s.p.a. project - Preliminary Analysis.

conceptual models and comparing them from the point of view of energy usage. In particular, the purpose is set to investigate whether there is an optimal shape of the building for optimising both the distributive aspects and limiting the solar radiation, guaranteeing however a good degree of natural lighting for the spaces used by the OCC personnel. An approximate evaluation of energy consumption is made and the impact of a photovoltaic system on the overall performance is analysed (Kota, 2014; Stumpf, 2009).

Once the phase of analysis of the preliminary project has concluded, a verification of the efficiency of the BIM tools is carried out in the phase of comparison of the various design solutions, generating several conceptual models and comparing them from the point of view of energy usage. In particular, the purpose is set to investigate whether there is an optimal shape of the building for optimising both the distributive aspects and limiting the solar radiation, guaranteeing however a good degree of natural lighting for the spaces used by the OCC personnel. An approximate evaluation of energy consumption is made and the impact of a photovoltaic system on the overall performance is analysed (Kota, 2014; Stumpf, 2009).

For the various alternatives a series of common conditions were set, such as a correct orientation of interior spaces, based on the awareness of a lesser incidence of solar radiation on the Northern fronts in comparison with the Southern ones (related to the latitude of the site, which lies between the Tropic of Cancer and the Equator), the placement of glazed surfaces only on the North-Eastern and North-Western fronts of the buildings (those which house the operators), the placement of 3 m deep horizontal eaves and hypothesising that the photovoltaic system will be placed on the South-Eastern and South-Western fronts (faced by the machinery rooms), as well as the entire covering.

The specific workflow adopted is analogous to that of the preliminary project: the only difference is that this time a modelling of conceptual masses in Revit® is carried out for each solution, which permits a quick functional analysis through the automatic generation of abaci of the areas for the verification of the correspondence to specific surface requirements.

Then the same mass models can be converted into analytic models, carrying out a selective export of data necessary for energy analysis, using a gbXML format.

The models thus obtained are therefore exported into the software IES VE®, where the bio-climatic analyses mentioned above are carried out, aimed at the identification of solar contribution, the conditions of natural lighting of the spaces which house the OCC personnel,

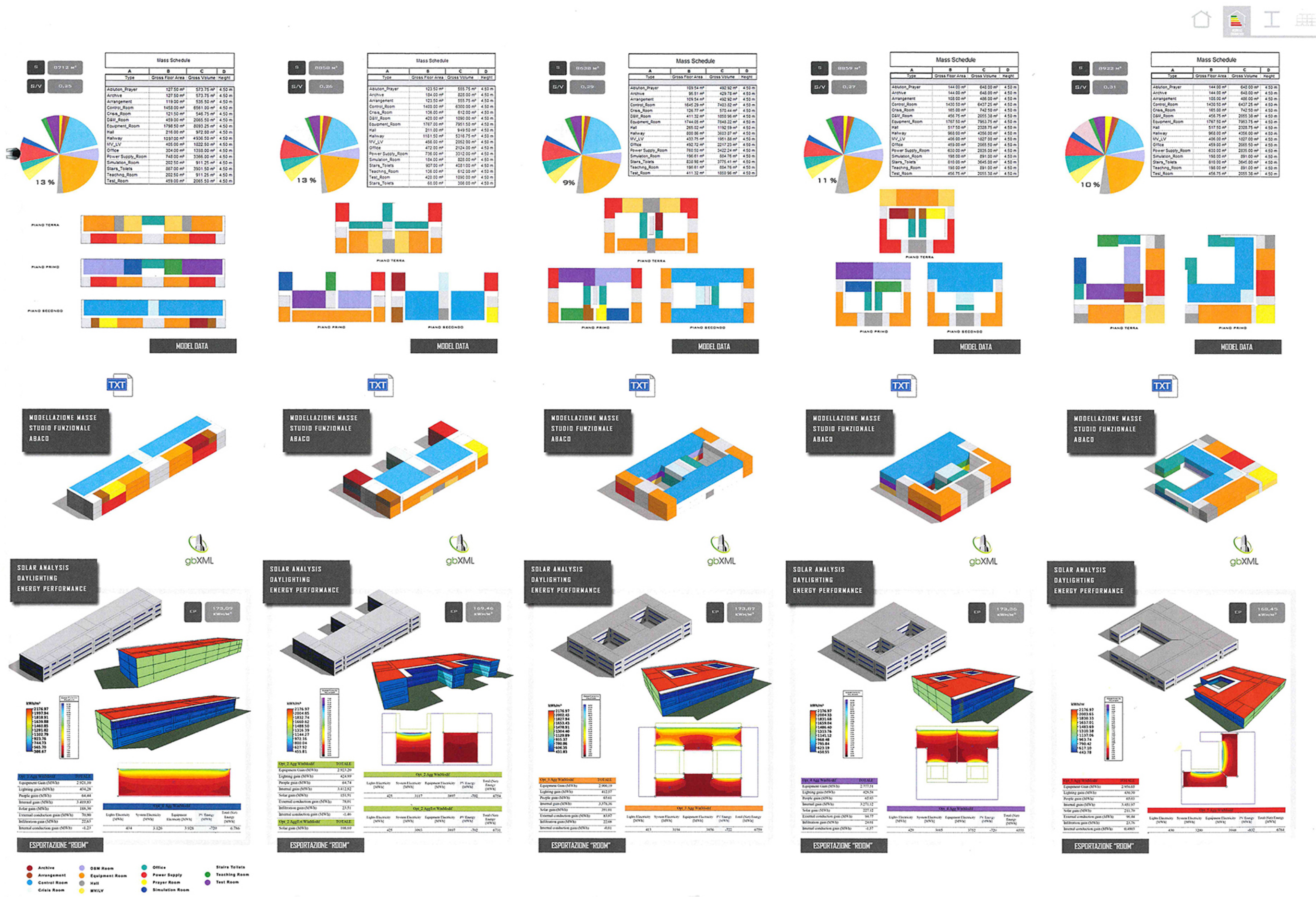

Figure 3. Design of alternatives - Rapid Energy Modelling for 5 design solutions.

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the productive potential of a photovoltaic system and of the index of overall energy performance.

he tested design solutions are 5 (Figure 3):

1. Solution corresponding to the preliminary project, modified in accordance to the bio-climatic approach described above;

2. “Comb” solution conceived for investigating the efficiency of the said parts of the building in the shading of the spaces between them;

3. Solution which retakes the traditional typology of the courtyard building, very common in those climatic contexts, with the possibility of control rooms in opposite positions, one facing the North-East and another the South-West of the building;

4. Courtyard solution in which the Control Rooms are one next to the other, both facing the North-East, which receives less solar radiation;

5. Solution developed on only two levels, unlike the precedent solutions, and conceived for assessing the impact of a greater extension of the photovoltaic system and a slight increase in the Surface/Volume ratio.

The results of the “Conceptual Energy Design” phase reveal how there is no solution capable of optimising at once all the design aspects considered for the comparison; from the analysis it is however evident that the variation in the extension of the photovoltaic system has a greater impact on the overall performance of the building in comparison to all the other design parameters considered.

Once the more efficient architectural solution in energy terms has been identified, the next step is the development of various constructive solutions. The design phase of the alternative solutions addresses in fact a dimensioning of the structures which, in this case, from the point of view of sustainability, is carried out for various building systems, assessing which among those examined may be more adequate for the project in question (Oti, 2015; Kensek, 2015).

The developed solutions are then assessed based upon various criteria: first of all the environmental impact during the entire life-cycle of certain materials or processes connected with certain building components is assessed; subsequently the compatibility of the building solutions with the architectural project is assessed, which derive, for example, from the absence of pillars within the large occupied spaces; finally, a comparison is carried out in terms of pre-fabrication, which is a very important aspect of sustainability, for cutting down costs and construction times of a project, as well as for bettering the work conditions in the work-site.

BIM system is still used for the analysis of environmental impact. Some tools offer an important support in the computation of materials and the calculation of the impacts, following once again the path of interoperability which, in an integrated process, involves the project of the structures as well. The BIM workflow regarding the structures is based on the construction of an initial physical model in LOD 200, characterised by geometric shapes of the transversal sections derived by a pre-dimensioning which, through the generation of an analytic model, can exchange information, taking advantage of the IFC standard format, with the structural resolution of the finished elements. Once the structure has been calculated and the features of the components modified, it is possible, thanks to the bi-directional nature of the process, to turn back through the analytic model, carrying out an updating of the physical model, which can reach a LOD 300. The updated physical model, including all the quantitative information regarding the components and materials, can be used directly for undertaking an analysis of the life-cycle of the structure and to assess its environmental impact (Eastman, 2011).

The first part of the process permits developing 4 different structural solutions in LOD 300 for the OCC, briefly described below (Figure 4):

1. Traditional solution in reinforced concrete (in line with the preliminary project), for which BIM families present in the software's database are used, from the rectangular beam to the pillar, to the pre-fabricated hollow-core slab in pre-compressed reinforced concrete; the latter used for maintaining the features of the individual elements, is modelled as a beam. The sections in reinforced concrete are modelled as wall elements.

2. Mixed structure in steel and cement, with hollow-core beams placed along the main reflecting surface, supporting pre-fabricated hollow-core slabs in pre-compressed reinforced concrete: the families used are hollow-core beams present in the software's database, while for the mixed pillars ad hoc families are used. The pre-fabricated hollow-core slabs in pre-compressed reinforced concrete are the same as those for the previous solution.

3. The third typology is entirely analogous to the preceding one, except for the fact that in this case the use of predalles slabs is envisaged: the beam and pillar families are thus the same as for case 2, whereas the floor slab is modelled as a “floor” element.

4. The last solution envisages the inversion of the framework of the beams-slabs, placing the first along the smaller reflecting surface and the others, once again of the pre-fabricated hollow-core type, along the larger one: the families used were the same as in solution 2.

Once the BIM model of the structures is complete a full comparative analysis of the environmental impact of each structure during its entire life-cycle is made, from the production of the material until its disposal, with the aim of choosing the “most sustainable” construction system (Eleftheriadis, 2015; Soust-Verdaguer, 2017). To this purpose the Revit® Tally® plug-in is used, which includes various categories of environmental impact; for the analysis of the life-cycle of the structure reference is made in particular to the Acidification Potential (AP), Eutrophication Potential (EP), Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Smog Formation Potential (SFP), and Primary Energy Demand (PED).

As in the “Conceptual Energy Design” phase, also in this case it is not possible to identify a solution that is

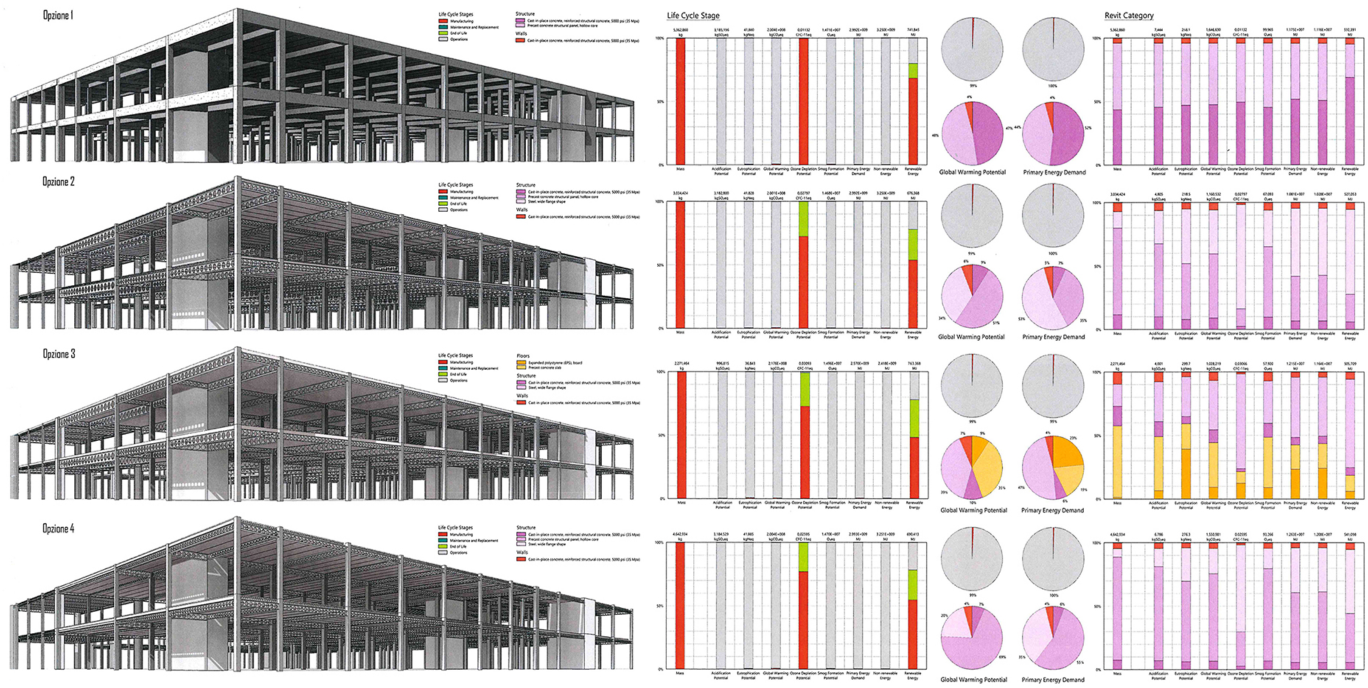

Figure 4. Design of alternatives - Analysis of environmental impact for 4 structural solutions.

clearly better than the others, considering the numerous and different categories of environmental impact.

Early Design. The next step is the Early Design, in which a BIM architectural and structural comprehensive coordination model is developed at LOD 200. It is in this phase that the first union of the two specialised models takes place, something which necessarily requires an accurate control of interferences among the various components (Aksamija, 2015; Eastman, 2011). From an architectural point of view the re-designed building develops along a main North-South axis, orthogonally to an East-West axis which places the building itself in the direction of Mecca. In this diagonal distribution of spaces, each floor has a clear separation in distributive terms between occupied spaces and spaces for equipment, most of the first facing the courtyard, which is the most privileged area of the entire structure, the others facing the South-East and South-West fronts, that is those most exposed to the sun.

In the insertion of an exterior covering over the courtyard, the synthesis of the solar analysis and of the projecting elements described previously may be used. The objective is that of creating a filter area between the inside and the outside which confers to the courtyard a strong architectural significance and protects the rooms from direct solar radiation; in order to guarantee both the protection from the sun and the natural lighting of the courtyard and the interior spaces, it was chosen to adopt transparent panels for the covering, characterised by a good luminous transmission and by a low solar factor.

The solar analysis for the optimisation of the geometry of the entire system is carried out directly on the BIM model in Revit®, paying special attention to the areas facing the interior courtyard. The verification of the efficiency in terms of natural illumination, instead, is made possible once again by inter-operability: the workflow followed in this case is the same for the energy analyses, with the difference that the initial model is no longer conceptual but architectural, and in it are defined the "rooms" to be exported to the analysis software through a gbXML format (Kota, 2014).

In particular, within the IES VE® the translucent panels of the roof are modelled specifying the solar factor and the luminous transmission and the assessment of the natural lighting conditions is carried out checking the degree of average lightings (lux) and its uniformity in the areas where work is undertaken which envisages the use of video display terminals. The design of the structure for the covering is based on remaining faithful to the main architectural theme, that of developing along the diagonal. A steel structure is envisaged for this with secondary beams placed parallel to the said axis, and main beams placed orthogonally to them. In order to confer architectural value to the covering, and thus to the courtyard, the use of tree-like pillars is envisaged. The pre-dimensioning of the exterior covering follows the same workflow as the structures, from the physical and analytic models to the FEM software and the updating of the initial BIM model.

Once the modelling of the exterior covering is complete, the next step is to unite the two different disciplinary models and to analyse the architecture-structure interferences: the two models may in fact be connected through a link which permits to keep them separate, yet visible within a single object. The modification of each of the linked models implies the updating of the overall model (Kensek, 2015). Linking the coordination model to the model of the exterior covering completes the Early Design phase (Figure 5).

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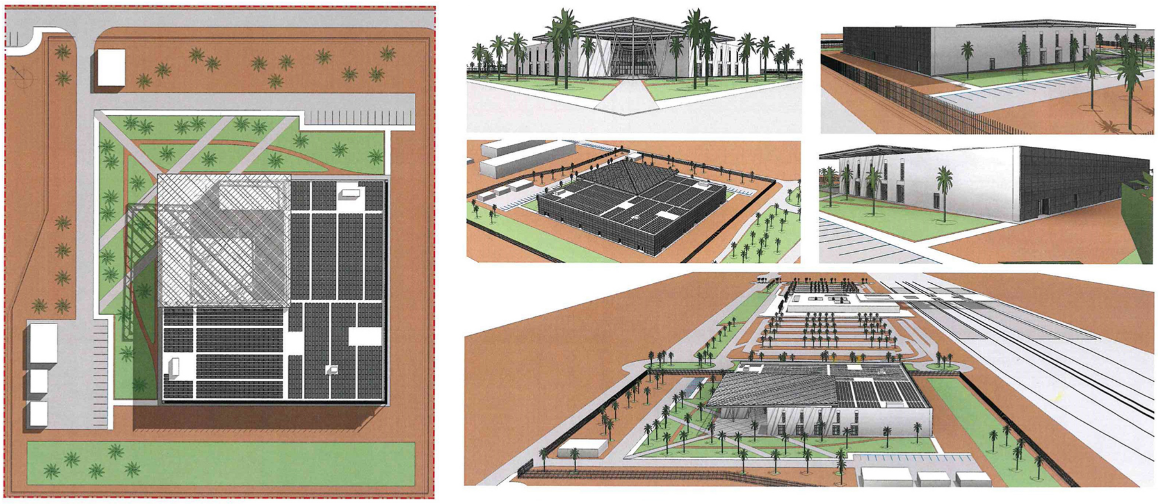

Figure 5. Early Design.

Detailed Design. In the Detailed Design phase the coordination model completed in the previous phase is continued in more depth. In order to reach a LOD 300 the various families that compose the building are modelled (Eastman, 2011).

In particular three categories of families are identified:

a. “system families”, which correspond for example to walls and floors, which are analysed in terms of optimal performance and stratigraphy with the use of the IES VE® software, and then developed in Revit®;

b. “hosted families”, to which doors and windows belong, that is those families which are necessarily housed within a mother family, such as a wall;

c. “loadable families”, which represent all additional external components, such as furnishings and photovoltaic panels, to be inserted in the overall model, completing it in all its parts.

One example of the first typology regards the exterior buffering, made of autoclaved aerated concrete, which gives the walls a solid mass and low transmittance. An interesting example for the third family type is represented by decorative panels in GRC envisaged for the protection of the North-East and North-West fronts from direct solar radiation. They are modelled as parametric generic families, placed within the overall model for its completion and for assessing their efficiency in terms of solar shading. The conformation and correct dimensions of the loggias certainly contribute to positive results.

Regarding the facades which face South-East and South-West, in front of the AAC buffering a photovoltaic facade in amorphous semi-transparent glass, modelled in Revit® is placed as a “Curtain Wall” element whose efficiency is once again evaluated on IES VE®. In order to assess the electricity effectively produced by the entire photovoltaic system, including the “stand-alone” panels of the covering, their placement is studied bearing in mind the obstacles and spaces necessary for the heat pumps and air treatment units for ventilation, as well as the shade offered by the exterior metal covering. It is understood that, for every small modification of the model (orientation, shading of the context, etc.), the model itself updates the energy performance.

With the modelling of the building with all its components and with the insertion of the various typologies of families, the maximum detailed reached is LOD 300 (Figure 6).

In order to increase the level of detail and development of the BIM model and of the information included in it, executive 2D drawings are carried out, and inserted directly as links, or “call outs” within the automatic sections: in this way, thanks to the potential of the two-dimensional design in terms of the relationship between level of detail and computational lightness of the models, it may be possible to reach a LOD 400.

Once the executive details are complete, the project is concluded with the calculation of the new index of energy performance derived by the optimisation of the form, of the transparent surfaces, and of the components of the shell and the system.

Results and Discussion

The analysis of the preliminary project shows the potential of BIM in the control of many performance parameters of a building in the design phase, revealing all the design problems associated to the lack of an integral multi-disciplinary approach during the initial phases of the process. This can be observed in the simple respect for the dimensional requirements of spaces, but also in the assessment of the efficiency of shading systems and in the orientation of the building itself.

The possibility of looking into a series of solutions in a quick and in-depth manner permits an accurate assessment of the most adequate form for a building based on the place in which it is set, thus joining current technological design methods to traditional bio-climatic methods, reinstating the strong and inevitable link between site and building. However, in the case study, the Index of Energy Performance does not vary significantly from one solution to the next, due to the destination of usage of the building, which means that the internal contribution of the machinery prevails clearly over the other elements in the

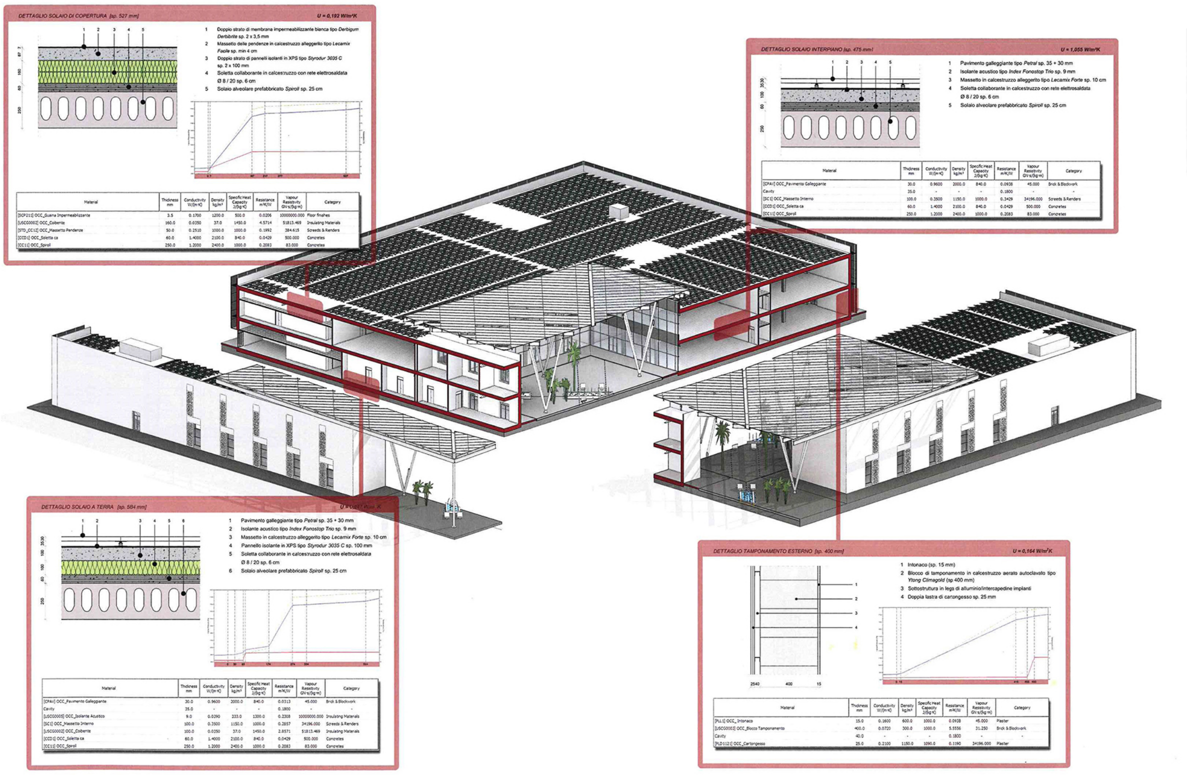

Figure 6. Detailed Design.

energy-balance. The aspect which has a greater impact on the overall performance, instead, is the production of photovoltaic electricity, and it is for this reason that the last conceptual solution analysed is the preferred choice.

What matters, however, is not so much the result of the said comparison with conceptual solution n. 5, but the process through which the said choice is reached: the efficiency of the BIM systems in making an innovative design easier, has been proven. It takes advantage of the result of the energy analyses not as simple means for assessment but as decision making tools and is capable of simulating the behaviour of the building, preventively identifying the problems derived from interferences between multi-disciplinary factors.

In this way a series of judgment parameters are available since the preliminary design phases, the assessment of which, without the use of BIM systems and their interoperability, would not be possible to obtain in a brief span of time and would be so expensive as to be almost certainly discarded. The same is true for LCA analysis of structural building systems, in which the automatic extrapolation of quantitative data on materials from the parametric models allows to include the subject of sustainability even in choice criteria and design of the structures, analysing a great amount of data in an expedite manner. On the other hand, the fact that the final choice is linked to requirements regarding pre-fabrication, shows how the said analysis cannot yet completely compute building aspect often of great importance for the economic success of the works.

During the phase of calculation of overall energy performance it is evident, once again and independently of the results obtained, that the assessments linked to the efficiency of the exterior covering, the type of shell and of system are possible, and especially in an expedite manner, thanks to the use of inter-operable BIM software. It is important to highlight, however, how the exchange of data between the platforms is not always efficient or even effective: in the case of the gbXML format, the conversion of 3D elements into surfaces makes the control of BEM necessary once the transfer has been completed, so as to avoid errors in the adjacencies between thermal zones; in the case of the IFC, on the contrary, the problems are mostly linked to the complexity of the structural models and their components, for example the hollow-core beams, which are not supported by the standard format and are therefore not transferred to the structural resolver.

Some considerations are finally necessary regarding the representation of models. Although levels of detail and development up to LOD 500 were envisaged, it is evident from the practical application that these objectives are not reachable for complex models if an adequate rationalisation is to be maintained, with the aim of allowing a correct management and an efficient usage of them. The cost of computing complex models with a high degree of detail, therefore, makes 2D drawings preferable to parametric modelling, especially in executive cases, making them more manageable and thus modifiable, leaving unvaried the potentials for use of the models, of which it constitutes a supplementary integration.

Conclusions

In view of the results obtained, especially in terms of method, a few interesting conclusion can be drawn. First of all, the analysis of a concrete case permitted experimenting with BIM applications on all key points of

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the sustainable project. For each phase of the process of the project it was evident how the use of BIM points toward sustainable design essentially because it permits the expedite management of great quantities of multi-disciplinary data associated to the project, eases the organisation of functions and process in terms of an integrated design and permits the quantitative comparison of various design solution from the preliminary design phases.

This last aspect permitted experimenting with an innovative design approach in which the preliminary choices were based on the results provided by energy and environmental impact analyses which normally would be undertaken at a much later moment of the design process.

On the other hand, the problems in managing complex BIM models must be stressed: the phase of preparation of the design alternatives provides a wide spectrum of assessment, however, due to the yet not perfect efficiency of the inter-operability, it may be very expensive, to such an extent as to be completely discarded in practice due its cost in both terms of money and time.

In this respect, despite its potential, the BIM must be enhanced in terms of efficiency – rather than effectiveness – in the transfer of data, both in terms of versatility and of the possibility of working outside precise methods of operation; the software used, in fact, are often too rigid, but especially too sensitive to possible errors in modelling or in the transcription of data in the standard protocols (IFC, gbXML, etc.), to the point of requiring a clearly greater degree of awareness by the designers, who must tackle problems that are no longer exclusively design-related, but also BIM-procedural and computational linked to the predisposition of the models or derived from the translation, during inter-disciplinary communication of languages that are often different.

Acknowledgements

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APPLICATION OF BIM IN THE CREATION OF PREFABRICATED STRUCTURES LOCAL PARAMETERIZED COMPONENT DATABASE

Qinghan Bai[1], Sihua Deng[1], Chenguang Li[2], Ze Qie[1]

[1] Beijing University of Civil Engineering and Architecture
Zhanlanguan Rd, 1, Dong Wu Yuan, Beijing, China

[2] Beijing Building Construction Research Institute Co.
Beijing 100084, China

[1] Corresponding author: 13366015526@163.com

Abstract

Introduction: As a research focus in the construction industry in recent years, prefabricated structures have advantages such as environmentally friendly and economical and so on, but it also increases the complexity of design and construction and the strict requirements for accuracy. **Methods**: Aiming at the shortages of prefabricated structures in design and construction, one solution is creating a local parameterized component database. Collecting the information of the required prefabricated components firstly, and based on this, we put forward a method of creating local prefabricated component database, including secondary development on API and customize parameterized component database, which based on the template file. **Results and discussion**: Combine BIM technology and prefabricated structures better to support the development of prefabricated structures.

Keywords

Prefabricated structure, BIM, Local parameterized component database.

Introduction

At present, the pre-assembly simulation works of prefabricated structures are remains to be studied. The BIM use for cost and project management has received more attention in the last few years and has now become a main focus of project owners (Feng, 2013). Although BIM has made great contributions to the construction industry so far, most of existing software tools are developed in the context of traditional non-prefabricated buildings and do not well take into account the new process that building components are produced in factory and moved to construction site for assembly (Leminen et al., 2013). Since the BIM software used by many domestic design institutes is mostly imported foreign products, there is a problem of software localization, and the parameterized component database should be localized as a core part of the software.

The first thing is collecting the data of components. Collecting detailed information of local prefabricated components from standard design atlas, design institute and prefabricated component factory, etc., to prepare for the localization of BIM software. The information of prefabricated components includes component size, material, price and thermal insulation performance, which lays a foundation for later information processing and analysis.

BIM serves as a useful platform for facilitating the on-site assembly services (OAS) of prefabricated construction for its benefits of providing collaborative working teams and decision makers with the physical and functional representations of prefabricated component (Chen et al., 2015). After collecting the product data from the component factory, parameterized component database in the modeling software can be localized. The process of localization is mainly established by secondary development or based on internal parameterized component database in BIM software. Since the software was designed to consider the expansion and compatibility issues in the early stage of development, this process can be directly performed. This component database is parameterized with well compatibility, so all kinds of components can be evolved by several basic types of components.

Since there is still no software that can contain all the building information, the common method is: basing on the Industry Foundation Classes (IFC) data model. IFC is a standard format which is open to the BIM data that are exchanged and shared among the software applications used by the participants to building sector or facility management (Richard, Jon, 2010). The industry foundation classes (IFC) standard achieves the data interchange between BIM tools (Wang et al., 2015). Using BIM software and BIM peripheral auxiliary software as the tool, coordinate multi-software and multi-specialty work, transfer data efficiently (Pei, 2010; Singh et al., 2011; Jung, Joo, 2011).

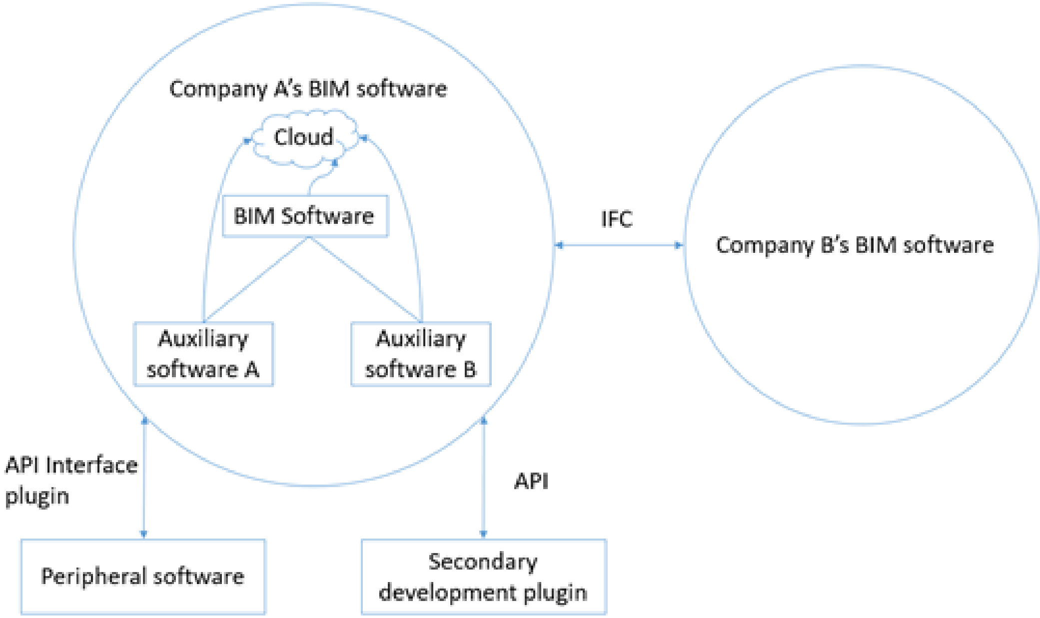

Figure 1. The collaboration relationship of BIM software.

The BIM software developed by IFC standard has good compatibility, and the data transmission between different companies are mainly relies on the IFC standard (Jeong et al., 2009; Lipman, 2009). Figure 1 shows the collaboration relationship of BIM software. The secondary development plug-in is compatible through the Application Programming Interface (API) interface, and peripheral software are compatible through the API interface plug-in. Usually, the building model and main building information are built by the core modeling software, but aiming at a certain specialty, the auxiliary software is needed to improve and transform the model.

Collect prefabricated component data

The component database is the core of the entire BIM modeling process and the entire lifecycle management of the building. Throughout a building's life-cycle this procedural transition is further expedited by BIM technology (Abanda et al., 2015). All project construction is realized by the combination of components. A prefabricated building is made up of many precast components, and these components are typically produced in a factory and transported to construction site for assembly [Kim et al., 2012; Kim et al., 2015; Hong et al., 2014). The parameterized components help data management and modification become easier, and data analysis is also derived from the support of the component database, which can be said to be the most basic building unit of the structure model.

Based on the previous collection of local component data, the local component database can be established in two ways: one is to use the API interface secondary development plugin to achieve localization; the other is directly using the component template file that contains in BIM software, customize the parameterized component database that conforms to the local situation. Both have their own focus, the former can achieve more complex and advanced functions, but it takes a lot of time and effort, while the latter is relatively simple and easy to use, and it is easy to quickly expand the component database. The process is conducive to promote the standardization, mechanization and informatization of construction and improve the environment of construction (Pons, Wadel, 2011).

The establishment of the local component database is based on the full investigation of the local products. the created precast components should also be saved to the standard parametric precast component library as this will simplify subsequent design works of prefabricated buildings (Arayici et al., 2011; Wang et al., 2016). In the investigation of the local prefabricated component products, various data information of the components needs to be collected, such as the information listed in table 1.

Table 1. Component information.

Geometric information	Other information
Component size (Length, width and height, etc.) Spatial location (Prefabricated component placement, installation, etc.) Connection location (Connected, parallel and vertical, etc.) ……	Material, Price Insulation performance Volumetric weight Application Identification and data ……

Secondary development by API

API means Application Programming Interface, which is an interface reserved for secondary development by the application, allows secondary developers to easily access the internal functions of the original program without knowing the details of its source code or its internal working system. In order to meet the different needs of

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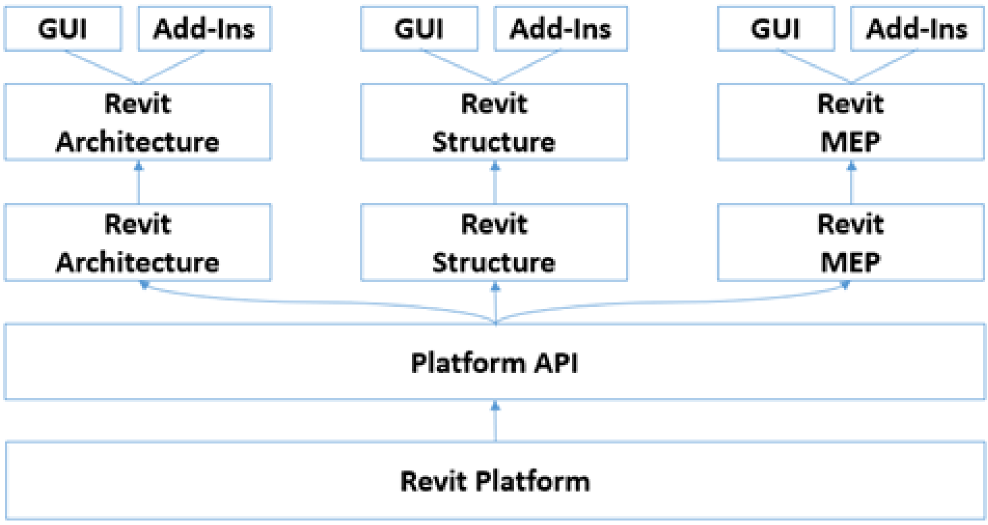

Figure 2. Schema-level diagram of BIM API theory.

various customers, the current mainstream BIM software has reserved rich and powerful API. We can integrate other applications through API or using API to redevelop our own applications. For example, the schema-level diagram of Revit is shown in Figure 2.

The bottom layer in Figure 2 is the development platform of the program. The code and functions internal the application cannot be accessed by external programs. It is the most basic part of the program. It mainly provides internal data access and graphic display functions. The upper layer is the core interface. Based on this, the Revit series of applications (Revit Architecture, etc.) are developed; on each application, the interface for the program is pre-reserved for the user, and through these interfaces, we can do further improve of the application that suits our needs.

Traditionally, split design of a prefabricated building is made by prefabricated-component factory after construction drawings are finished by architectural design firm (Fan, Li, 2014). By using the API, we can improve the efficiency of the operation of the BIM model: First, we can access the BIM model more precise, and the target object can be quickly found through the combination of the object filtering class function, Filtered Element Collector, and the filter condition. Secondly, the speed of modifying BIM model can be optimized by batch processing the model. By running all the commands in the API plugin and then performing a unified model update, the time lost by the original model real-time update is reduced. Finally, by using the transaction mode to ensure that the API program commits or discovers problems without error. Guarantee access performance and functionality better. At present, the application direction of API secondary development mainly focuses on the following aspects (Autodesk Asia Pte Ltd, 2012):

1. Replace some mechanical operations in the original program;
2. Develop interface for compatibility with other software;
3. Extract model data for data optimization analysis or export data reporting;
4. Link the external information of the converter to complete the drawing of the primitive or the change of the parameters;
5. Accomplish the automatic error checking of model file based on design specifications.

Secondary development of the Revit API requires the .NET development language, such as Visual Basic.

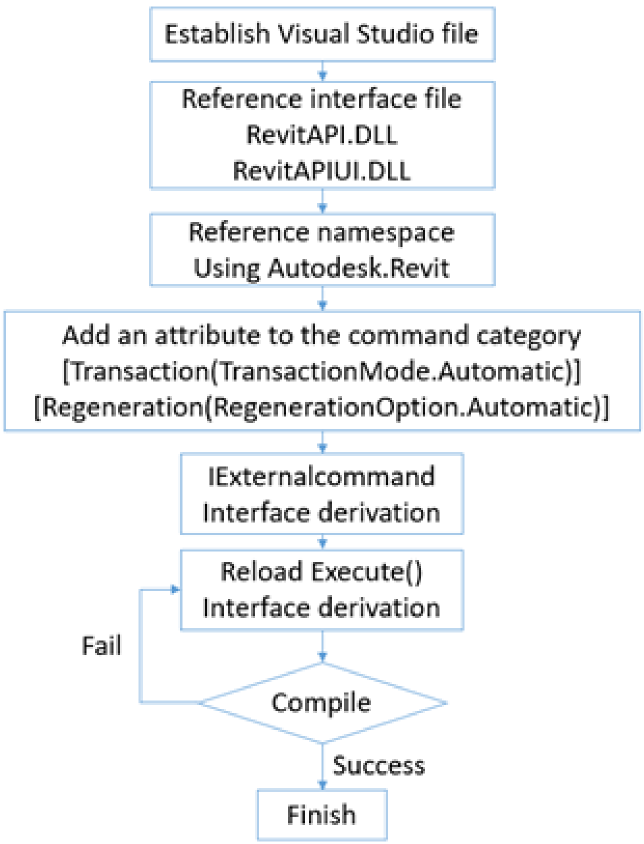

Figure 3. Basic flow of API secondary development.

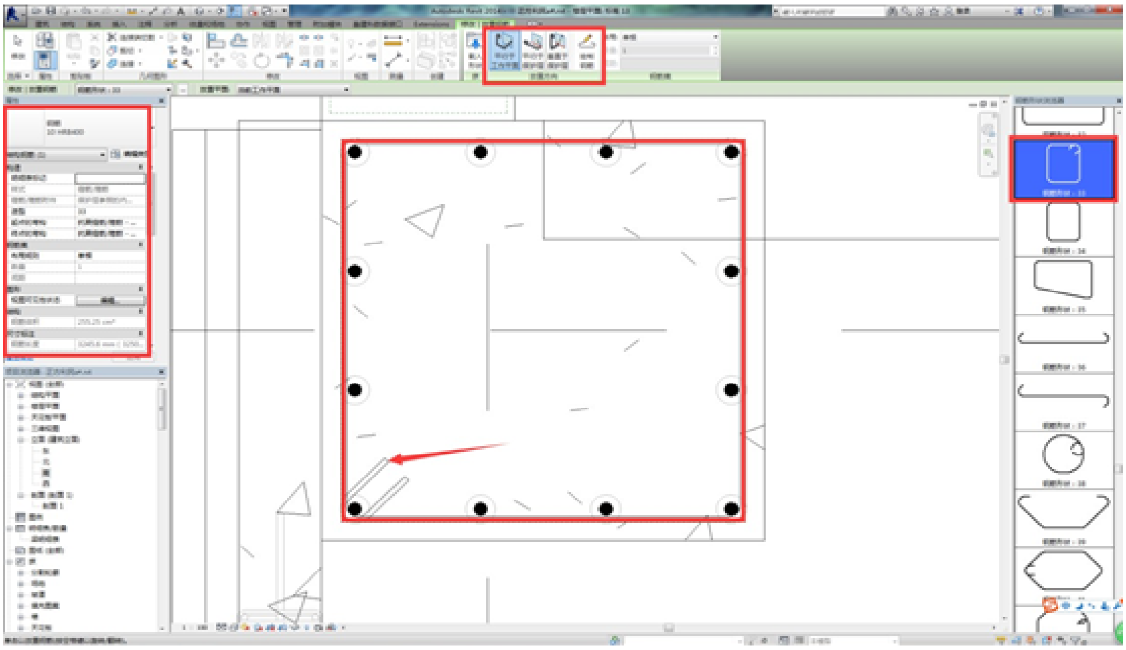

Figure 4. Arrangement method of reinforcement in the original program.

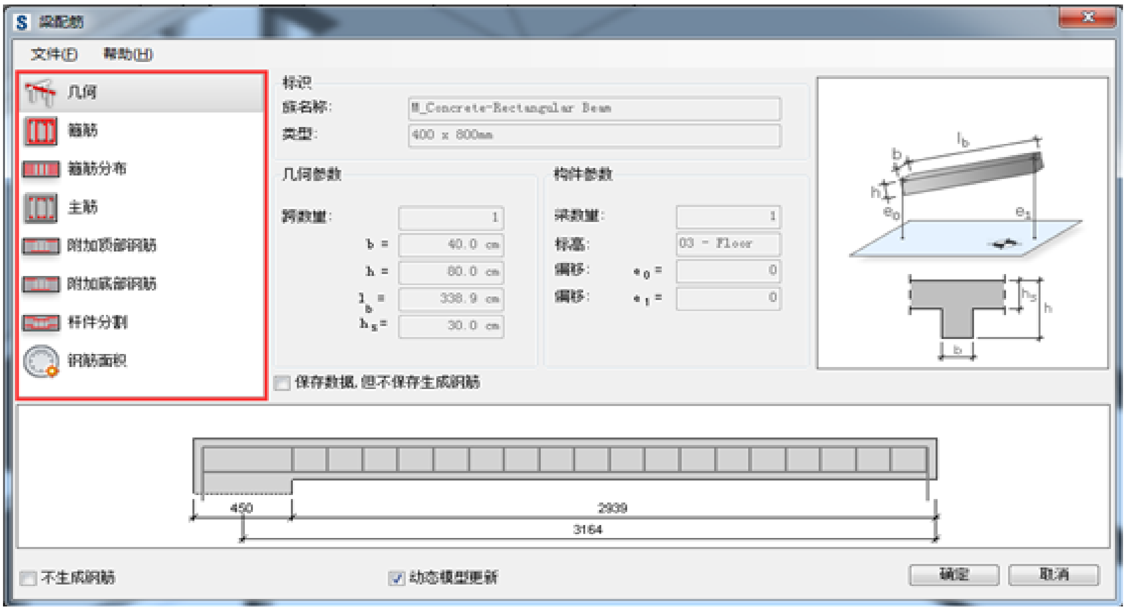

Figure 5. Operator interface of parametric arrangement of reinforcement.

NET, C# or C++/CLI. The secondary development plug-in can be divided into two types: external command plug-in (IExternalCommand interface), this plug-in loaded into the Revit program when Revit starts, created a Revit command by manual call; external program plug-in (IExternalAppllication interface), which is automatically called by the corresponding Revit startup and shutdown events, used to add menus and toolbar or other initialization commands. In most cases, an external command plugin is used. The basic flow of API secondary development is shown in Figure 3.

At present, the improvement of the component database by API secondary development is mainly reflected in the rapid modeling based on the component database. The following part shows how to use the API plug-in to improve the modeling efficiency.

Taking Revit structure rebar modeling as an example, the layout of the rebar model in the original software is mainly manually selected on the 3D solid model section, with many control options and complicated operation (Figure 4), and the large amount of steel bars and the complexity of modeling leads to many problems in the applicability of this method: the modeling operation is complicated and inefficient, and the accuracy is low, etc. In response to solve the above problems, a parametric reinforcement interface plug-in has been developed based on the API.

The plug-in can avoid the problem of precise low result caused by manual selection on the original three-dimensional model, and at the same time, the various options are concentrated on one interface, and the operation is relatively simple and convenient. Improve the

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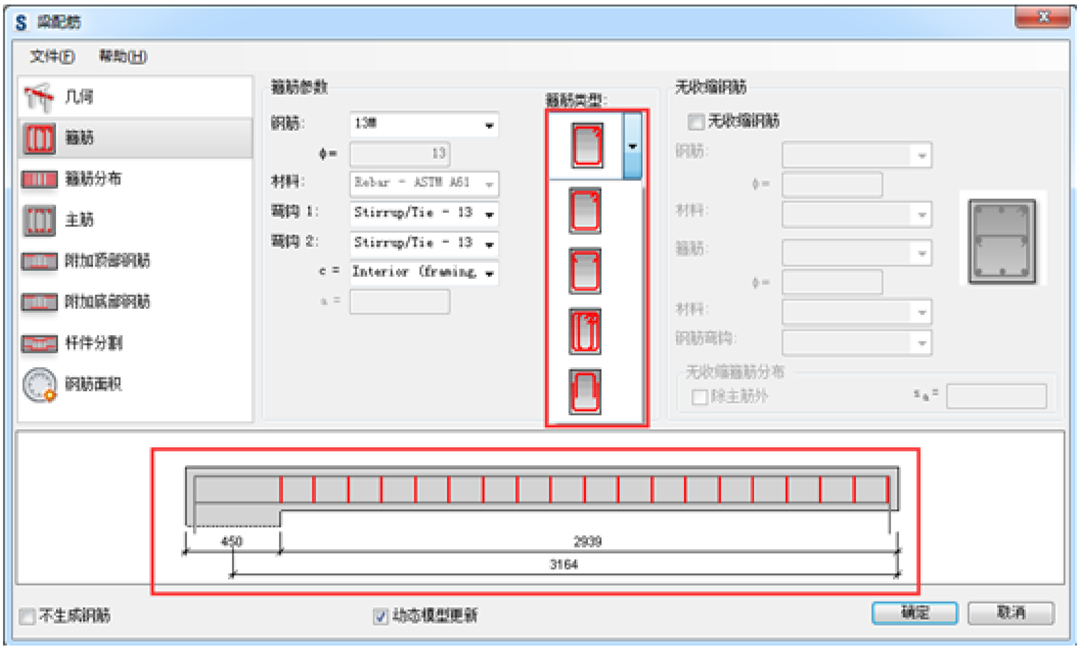

Figure 6. Parameter setup of hoops.

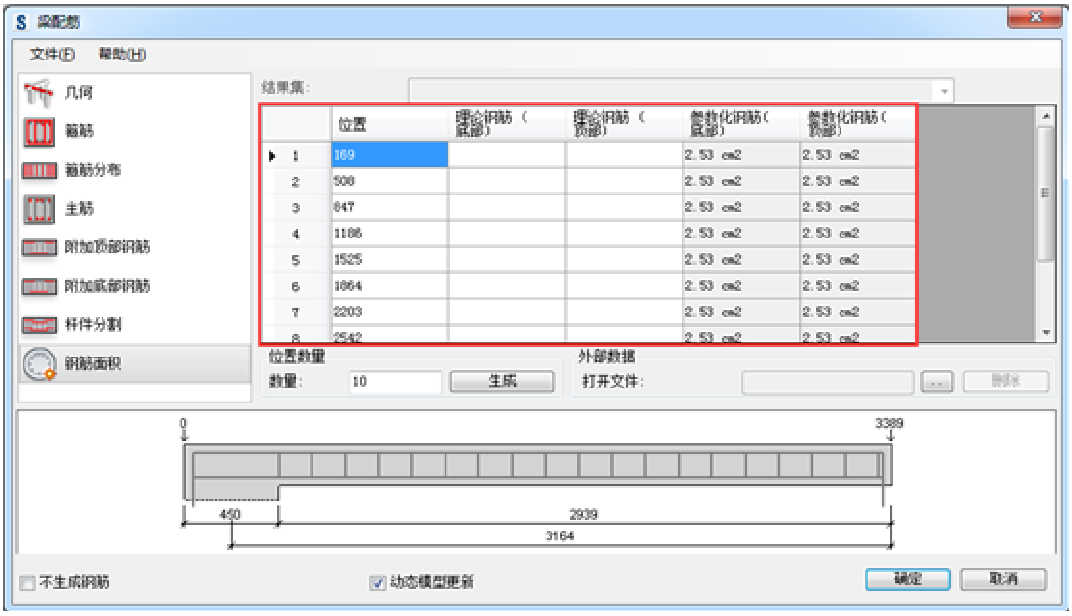

Figure 7. Bar area options.

efficiency of steel modeling (Figure 5). Any modifications in building design will be automatically reflected in other related parts (Park, 2011).

Taking the beam reinforcement as an example, the various options required for the reinforcement of the beam are listed on the left side of the interface. The first item is the geometric information, and the program automatically extracts the relevant geometric information of the member to be reinforced, including the family name, type, geometry parameters and component parameters, etc., the second to seventh items are the parameter options of the steel bar arrangement, rebars of various diameters, types, positions, configurations can be selected directly by adjusting parameters, and there are schematic diagrams on the lower side of the interface to assist us. Perform the reinforcement operation (Figure 6). The last item is the statistics of the area and type of the reinforcement, which is convenient for later calculations (Figure 7).

Custom parameterized component database based on template file

Template file, which is the template that comes with the original program to create parameterized components.

The file basically covers the various settings and related graphical representation styles of the parameterized components, thus avoiding the complicated programming process of the secondary development of Application Programming Interface and facilitating the user to quickly establish corresponding components adapted to their own needs. Because the establishment of local parameterized

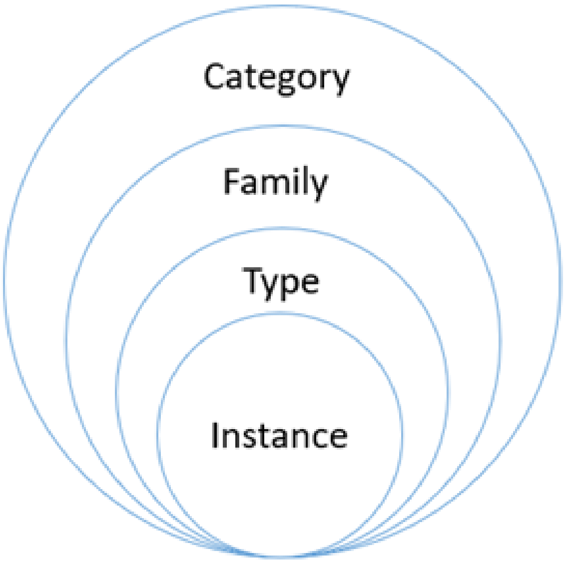

Figure 8. Hierarchy diagram of graphic element.

component database has a large workload, and the template file of the BIM modeling software can basically cover the required basic parameters, this paper mainly uses the method of this section to establish the local component database.

The following part is a demonstration of establishing a component database using Revit as an example.

Organization of primitives

The primitives, which is the various display units that exist in three or two dimensions in the BIM model, such as a column or an axis, can be referred to as a primitive. In Revit, we call the component "family", and the component database is called "family database". Autodesk's official interpretation of the "family" is: "family" is a set of primitives that contain a common set of parameters and corresponding graphical representations.

Some or all of the parameters of different primitives in the same group may have different values, but the set of parameters (its names and meanings) are same, and these variants in the family are called family types or types (Qiang, 2011; Huang, 2013).

In the real engineering project, the number of primitives in the project is extremely large. If the user does not make the corresponding rules, it will lead to confusion in data file management. Therefore, in Revit, all the primitives are logical according to a certain level. Organized together, the classification hierarchy is category, family, type and instance.

Categories are the highest level when categorizing primitives. Categories represent different sub-items of the building model. For example, foundations, columns, and beams in buildings are represented in Revit as three different categories: structural foundation, structural column, and structure framework, the category is preset in the program, and cannot be changed.

Categories are classified into different families. For example, “structural beam category” includes steel beam family, cast-in-situ concrete beam family and precast concrete beam family, among which “precast concrete structure beam” can be classified into different families such as shapes, sizes, uses, etc. A family is a grouping of primitives based on the same use and similar graphical representation of the parameter set (Liu et al., 2009). Some attributes of different primitives in a family may have different values, but the settings of the attributes (the names and meanings) are the same (Qiang, 2011; Huang, 2013).

Family can be classified into different types. "Type" is a hierarchy that classified elements with different parameter values within a family. For example, different precast concrete beams may have several different sizes and shapes, so that in this family of precast concrete beams, there are several different types, such as 300mm * 600mm and 300mm * 700mm, etc. These specific types are different types of precast concrete beam families.

Finally, each "type" can be placed multiple times in the project file according to different settings, such that an item (single primitive) placed in the project becomes an instance of the type, the same one structural column can be placed in one layer or in three layers, which are two different examples.

The relationship of primitives is shown in Figure 8.

Family parameters

The family parameter is a variable that controls the common attribute of the component size, shape and material, etc. In the project, the attribute of the family can be adjusted or modified without using the family, which ensures the applicability of the parameterized component and the convenience of later data extraction.

When creating a local family database, selecting different family templates will have different family parameter settings. The setting of the family parameters reflects the user's intention to create the family's expected performance in the project. In Revit, all family changes are driven by family parameters.

Table 2. Family parameters.

Parameter Type	Description
Text	Enter characters to define literal parameters
Integer	A value expressed as an integer
Numerical value	Used for various digital data, is real number
Length	Create the length of the primitive or sub-component
Area	Create the area of the primitive or sub-component
Volume	Create the volume of the primitive or subcomponent
Angle	Create the angle of the primitive or subcomponent

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Table continuation 2

Slope	Define the slope of the parameters
Currency	Define the currency of the parameters
URL	Provide a web link to a user-defined URL
Material	Specify parameters for a specific material
Yes/No	Use "yes" or "no" to define parameters that can be used in conjunction with conditional judgments.
Family type	Nested components, different family types can match different nested families

Test of the family

The main purposes of testing the component library are as follows:

First, make sure that the family file has good parametric performance. Testing the parameters and variables of the family file ensures that the family file has stable parametric performance in the actual project.

Secondly, ensure that it meets the domestic architectural design and the company's internal drawing specifications. With reference to the Chinese architectural design codes and atlases, as well as the company's internal drawing specifications for line types and legends, the display of family files under different views and precisions can be checked to ensure the final quality of the project documents.

Thirdly, achieve the unity of family file. The first two tests are the key to ensuring the quality of the family files, and they are indispensable. However, the test of the uniformity of family files does not directly affect the quality itself, but if you pay attention to the uniformity setting when creating family files, it will be very helpful for the management of family files. Moreover, after the family file is loaded into the project file, it will also bring some convenience to the creation of the project file:

On the one hand, ensure the unity of family documents and project templates. After the family file is loaded in the project file, the information that comes with the family file, such as "Material", "Fill Style" and "Line Style Pattern" will be automatically loaded into the project file. If the project file already contains information with the same name, the information in the family file will be overwritten by the project file.

Therefore, when creating a family file, we should try to refer to the information already in the project file. If there is a need to create a new file, the naming and settings should be consistent with the project file to avoid redundant information.

On the other hand, ensure the unity of the family files themselves. Some settings of the specification family file, such as insertion point, saved thumbnail, material, parameter naming, etc., will facilitate the management of the family database and loading the project file to make the information contained in it uniform.

The testing process of the family can be summarized in one sentence: according to the requirements of the test document, the family files are tested one by one in the test project file environment, the family editor environment and the file browser environment, then a test report is generated. The main content of the test document includes four aspects: test purpose, test method, test standard and test report.

The main test process is as follows:

1. Formulate test documents: there are different test methods of different types family files, we can first classify the family files in 2D and 3D. Because the 3D family file contains many different family categories. The creation process of the partial family category, the family template function and the modeling method are highly similar.

For the 2D family file, the creation process and the family template function of the detailed component are typical, so based on this category, two-dimensional universal test document is formulated. "Title bar", "comment" and "contour" have certain specialties, we can add or delete some specific test content and make related documents based on two-dimensional universal test document.

For the 3D structure family, in addition to the parametric test and the uniformity test, some special settings in the structure family should be checked, because these settings are related to whether the structure family behaves correctly in the project. For example, check that whether the end points of the concrete structural beam are locked with the two reference planes "component left" and " component right" in the template, and so on.

Then, various types of structure families can be loaded into the project to check whether the family behavior is correct, for example, the connection of structural column and beam, which built in same material or different materials; analysis the model, check whether the steel protection layer is correct, etc.

2. Create test project files: For different categories of family files, we need to create corresponding project files during the test, simulate the call process of the family files in the actual project, and discover possible problems.

3. Test in the test project environment: Load the project file to check the display and performance of the family files in different views. Change the family file parameters and system parameter settings to check the parametric performance of the family file.

4. Test in the family editor environment (Liu et al., 2009): Open the family file in the family editor, check the unity between the family file and the project template, such as "material", "fill style" and "linear pattern". And check the unity between family files, such as insertion points, materials, parameter naming, etc.

5. Test in the file browser: In the file browser, observe the display of thumbnail and check whether the file size is within the normal range according to the file properties.

6. Complete the test report: Refer to the test criteria in the test document, mark the wrong items one by one,

and complete the test report to facilitate the next file modification.

Conclusions and future work

BIM technology and prefabricated structures are two of the most popular technology branches of the recent construction industry, injecting vitality into the construction industry. BIM technology is very suitable for the concept of detailing and industrialization of the prefabricated structure. This paper shows the establishment of local component database of the prefabricated structure based on Revit. As the basis of BIM technology, the establishment of local component database is a focus of localization of BIM technology.

This paper introduces the method of building Revit parameterized component database and studies the naming rules and testing of component library. Secondly, through API, the form of secondary development plug-in, avoids the cumbersome modeling process of Revit's original steel modeling tool, and realizes the integration and parameterization of steel reinforcement modeling.

The combination of BIM technology and prefabricated structure is a complex and huge system engineering, focusing on the application of the whole life cycle of the building. This paper has done in-depth research and discussion on the basic problems in the system engineering, but further research is needed in the follow-up of the overall workflow.

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3D EARTHWORK BIM DESIGN AND ITS APPLICATION IN AN ADVANCED CONSTRUCTION EQUIPMENT OPERATION

Jeonghwan Kim[1], Heeyeon Kim[2], Waqas Arshad Tanoli[3], Jongwon Seo[4]

[1] KyungPook National University
80 Daehakro, Bukgu, Daegu, Korea

[2,3,4] Hanyang University
222 Wangsimni-ro, Seongdong-gu, Seoul, Korea

[4] Corresponding author: jseo@hanyang.ac.kr

Abstract

Introduction: Advent of new technologies leads the construction industry in utilizing the modern techniques, especially in the earthwork process. The machine guidance system is one of such examples which allows the operator to work more efficiently by using the design on the display screen. **Methods**: This paper outlines a new Building Information Modeling (BIM) approach to earthwork design with the development of module system which calculates the actual earth volume and generates a TIN surface for machine guidance. This method has importance in generating Triangular Irregular Network (TIN) surface which can be used for visualization of the 3D model as well as for the machine guidance. **Results and discussion**: The integration of IT based system with the earthwork site results in higher efficiency and productivity. In earthwork process, the proper flow of information is essential as it can increase the transparency and lead to process improvement. This module provides an easy approach for the model generation with its user-friendly interface.

Keywords

BIM, Machine guidance, Earthwork, Construction equipment.

Introduction

Earthwork operations possess a significant value in any construction project and can cost about 25% for the overall project budget (Hare et al., 2011). The estimation and planning for earthwork operations directly impact the cost and duration of the project, and these operations signify the success and failure of the project, which implies that the earthwork quantity takeoff play an important role in a construction project(Smith et al., 2000). Accordingly, accurate estimation of earthwork volume is essential to assess the number of equipment, construction period, and construction cost to be used for construction. With regard to accurate estimation, various methods were used to calculate the earthwork volume at the design stage of the construction project.

In the earthwork design phase, generally, there are two conventional earthwork estimation methods; Average End Area (AEA) method and surface-to-surface method. Their estimation accuracies are, however, not compatible to the Digital Terrain Model (DTM) based estimation due to its neglecting nature of interpolation. Therefore, to obtain reliable earthwork quantity takeoff outcomes, Digital Terrain Model (DTM) based earthwork estimation system is required. Indeed, earthwork estimation software using cross section or TIN prism to calculate earthwork volume have been developed substantially. For example, Civil 3D developed by Autodesk, Key TERRA developed by KTF software, and many others are available as an automated tool. These programs have functions to conduct 3D earthwork modeling using topographic information and quantity estimation of cut and fill. Such automated softwares are now increasingly used.

In addition, in the construction phase, the advent of new technologies also leads the construction industry in utilizing the modern techniques, especially in the earthwork process. The machine guidance system is one of such examples which allows the operator to work more efficiently by using the design on the display screen. The operator can use 2D or 3D design which helps in eliminating the traditional surveying methods which can create hindrance in the smooth operations, the 3D digital terrain design model is usually used for machine guidance. These models provide the information regarding elevation and terrain design to the operator through digital screen mounted in the cabin of earthmoving equipment. Many researchers have identified the enhanced quality and productivity in the construction projects using automated machine guidance (Jonasson et al., 2002). The modeling for the machine guidance system also improves the planning for the construction process with less rework

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on the designed model (Barrett, 2008). Use of such technology provides higher accuracy with less time and reduced cost. The operator of the earthmoving equipment can effectively visualize and move around the site using equipment position on the design model (Baertlein et al., 2000).

Although 3D earthwork estimation software has been used for many projects during construction phase, to date, the seamless integration between 3D earthwork design information from the 3D earthwork estimation software and machine guidance operation has not been considered. More specifically, inputting design information into the machine guidance is unnecessarily required for the machine guidance operation. For example, the current machine guidance operation uses manual information transfer via flash drive or e-mail to utilize the design information (.dxf file) for machine operation. It causes disconnection of information between design phase and construction phase, which leads to inefficient, time-consuming, and unnecessary operation.

This paper outlines a new Building Information Modeling (BIM) approach to earthwork design with the development of module system which calculates the actual earth volume and generates a TIN surface for machine guidance. This method has importance in generating Triangular Irregular Network (TIN) surface which can be used for visualization of the 3D model as well as for the machine guidance. Conventionally, the conversion of the 2D model to 3D is a cumbersome and tedious process (Vonderohe, 2009). The module is developed using visual basic programming and is compatible with the CAD based commercial software. Also It is capable of targeting formation level, slope generation, volume calculation, and the creation of a model for machine guidance. The machine guidance technology has replaced the staking process and labor intensive survey work (Hammad et al., 2013). This technology is primarily used for earthwork projects. However, it is also useful for other operations like paving and lifting (Kirchbach et al., 2012). The integration of IT based system with the earthwork site results in higher efficiency and productivity. In earthwork process, the proper flow of information is essential as it can increase the transparency and lead to process improvement (Peyret et al., 2000). This module provides an easy approach for the model generation with its user-friendly interface (Tanoli et al., 2017).

Developing a 3D Earthwork BIM design Software

This paper presents a new BIM-based module for earthwork operations. Visual Basic 6.0 is used as the main software language for the development of this module, and it uses Windows operating system. The system is developed in conjunction with CAD engine to produce 3D shape information. This module is an independent program and compatible with the other commercial design software like Autodesk Civil 3D. This research presents the formatting level based technique for the modeling of earthwork design. It applies the volume calculation method which uses projection and interpolation for accurately calculating the earthwork volume. The earthwork design system components are presented in Figure 1.

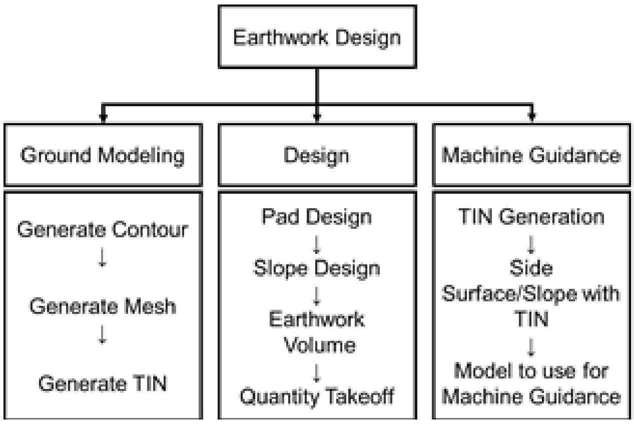

Figure 1. Earthwork design system components.

The module has simple and user-friendly graphical user interface (GUI) which is shown in Figure 2. It has import function through which ground surface in the form of contour or TIN can be directly imported. It is also capable of importing point cloud data using .mdb file and generate the ground TIN surface. The formatting level surface is created by providing the design elevation with co-ordinates information. The formatting level based design can also be drawn on the topographic model with the desired altitude value, as all the points on formatting level have the same elevation.

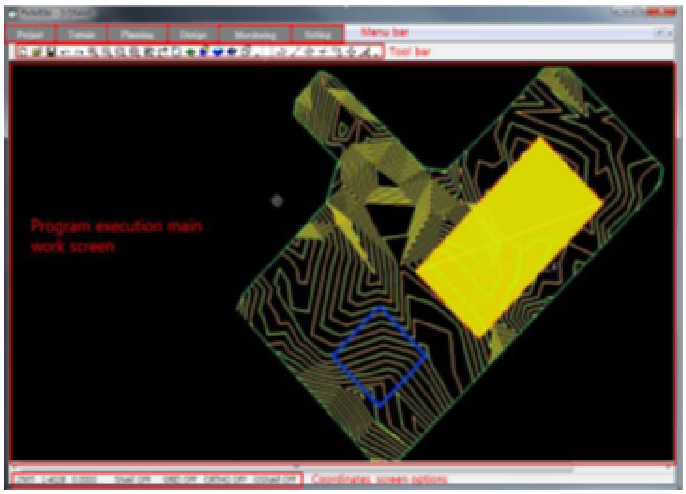

Figure 2. Module main screen.

The TIN surface is automatically created using points in the formatting level area. However, the next step in the design is to connect the formatting level with the existing ground surface for which the projection angle is required. Depending on the site requirements it is possible to generate the projection from the formatting level surface in vertical or slope form, as the system can calculate the volume in each case. The program can calculate the cut and fill volume at any given section along the length of design formatting level. The process of volume calculation is explained using flow chart in Figure 3.

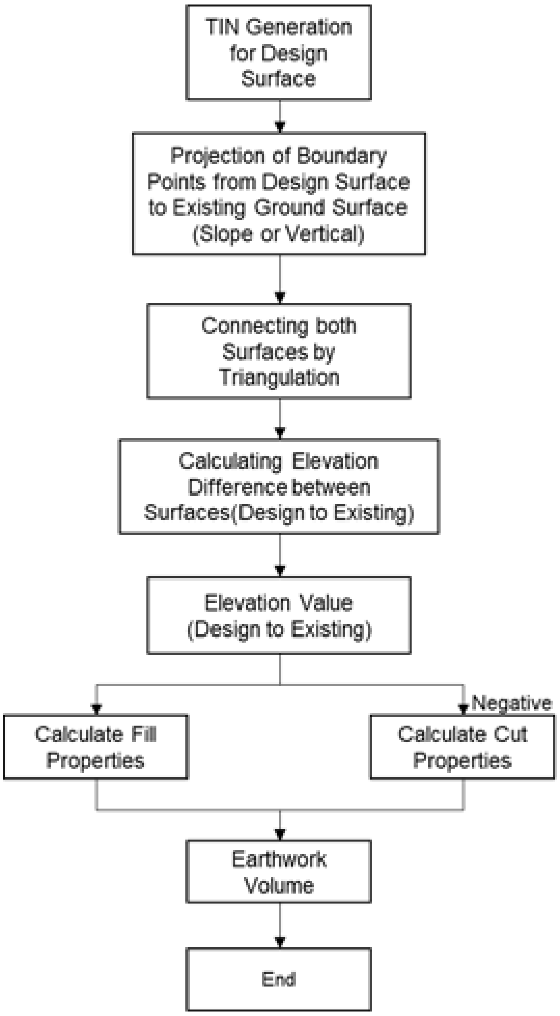

Figure 3. Flowchart for volume calculation of 3D model.

Traditionally, average end area method is used for volume calculation based on the average area between two consecutive cross sections.

$$V = \frac{L}{2} \cdot [A_1 + A_2] \quad (1)$$

where A_1 and A_2 are the areas of cross-section and L is the distance between these cross-sections. It is challenging to use this method continuously for the nonlinear sections (Slattery et al., 2012). However, this module used the surface to surface method for better accuracy. A new surface elevation is calculated based on the difference between two surface elevations using the location where the edges of triangles intersect the two surfaces as shown in Figure 4.

It is important to know the elevation difference between existing and planned ground surfaces. The existing and proposed ground TIN surfaces are created using survey and design data. In the case of the formatting level projection with no slope to the existing ground surface, the triangular network for side wall is generated between two surfaces. In this case, ground and design model share the same (*XY*) coordinates with the only difference of elevation.

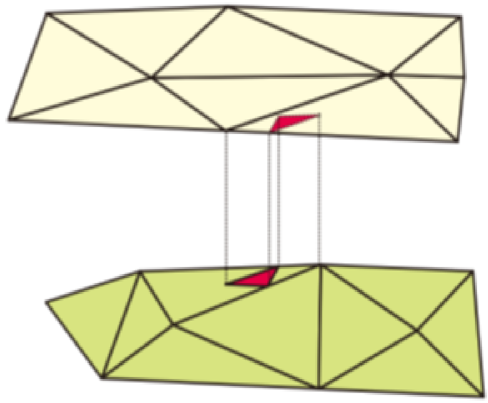

Figure 4. Surface projection illustration.

By using **Z** (elevation) value, the quantity can be estimated by triangular columns volume. If the formatting level elevation value "Z" is lower than the ground TIN surface the volume is calculated as Cut, however, if the designed formatting level is located at a higher elevation than the ground surface, the fill volume is calculated.

A polyline is drawn along the formatting level surface in a longitudinal direction from one end to the other for dividing the area into equidistance stations. The module also provides the equipment monitoring function. The design drawings in the module are saved in a .dwg file format which is converted into a .dxf file using Autodesk Civil 3D. The 3D design model with DTM (Digital Terrain Model) is then available for use in the machine guidance system.

Case Study: Integration to the Machine guidance

The following case study aims to check the practical application and the validity of developed module system. The model is designed using the formatting level based module and is verified on site for use in machine guidance system.

A site in Seoul, South Korea is selected as a pilot project to test the developed module system. The area under study is not in regular rectangular shape. The site topographic data is collected using laser scanning, the 3D laser scanning technology provides higher density data as compared to traditional surveying methods. Ground contour data is imported into the module and using its TIN generation function the surface is converted into TIN. Figure 5 presents the original ground surface model in contour and TIN form.

A rectangular area is selected, and formatting level design is drawn on the BIM-based topographic model. The formatting level dimensions are based on required length and width at the site. The design altitude value is then provided to the formatting level, as the whole surface have same elevation value.

According to design and site requirements, it is possible to design in slope and vertical form, and the system is capable of calculating the volume in both cases. Figure 6 shows a formatting level design with the slope, projecting to the existing ground surface. The outer boundary is

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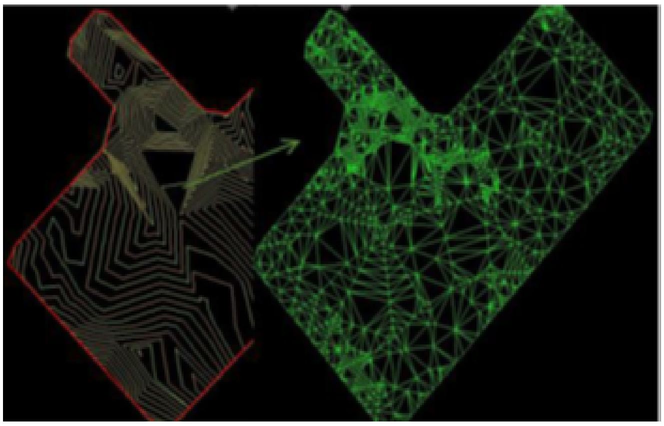

Figure 5. Ground surface model in contour and TIN form.

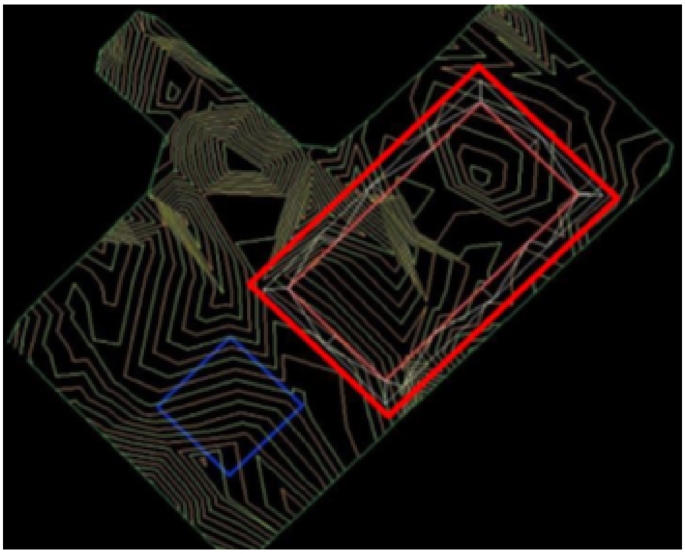

Figure 6. Formatting level based design with existing ground surface.

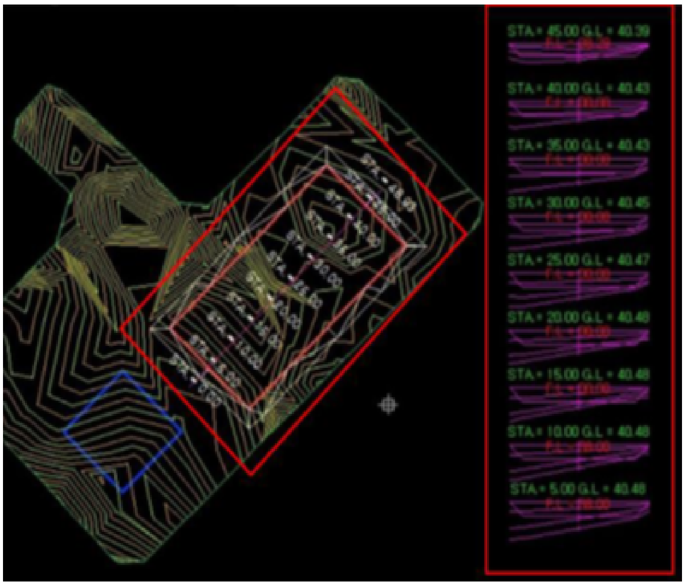

Figure 7. Formatting level design with station information.

indicating the connection with the existing ground surface, and inner rectangular marking depicts the formatting level design surface.

The formatting level design surface is then divided into stations along its length as shown in Figure 7. The ground

Figure 8. View of machine control panel.

level elevation can be seen at any station. It provides the function to divide the formatting level into stations with equal or different length. The formatting level based design file having TIN surface is imported in Autodesk Civil 3D and saved in .dxf file format. The machine guidance control panel requires the TIN file in .dxf file format.

The files with TIN surface are only visible in the control panel of earthmoving equipment. The formatting level design file is then imported into the machine control panel. Figure 8 shows the view of machine control panel for the operator in the earthmoving equipment.

Conclusion and Future Study

This paper outlines a new Building Information Modeling (BIM) approach to earthwork design with the development of module system which calculates the actual earth volume and generates a TIN surface for machine guidance. Visual Basic 6 is used for development of this module in conjunction with the CAD engine. The topographic modeling function supports 3D BIM design using the point cloud data obtained from laser scanning. It is possible to draw and design a formatting level on the 3D ground with consideration of slope and vertical planning. For the volume calculation of cut or fill in between formatting level design surface and existing ground, this module used the surface to surface method for better accuracy.

The developed module is capable of creating a TIN model for use in machine guidance system. A case study has proved the validity and effectiveness of this module for earthwork design. The module at this time can only deal with TIN models, however, with the integration of algorithm for solid and parametric modeling technique, its usability will increase.

Further studies are in progress to update this formatting level based BIM module, incorporating the 4D (time) and 5D (cost) design functions to automate the calculation of time and cost at any particular section. The large scale validity assessment will also be carried out in projects with different cost and duration.

Acknowledgement

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OBJECTIVES OF THE QUALITY CONTROL SYSTEM FOR CONSTRUCTION AND INSTALLATION OPERATIONS IN VIETNAM

Thai Nguyen[1], Antonina Yudina[2]

[1,2] Saint Petersburg State University of Architecture and Civil Engineering
Vtoraja Krasnoarmejskaja st., 4, St. Petersburg, Russia

[2] Corresponding author: yudinaantonina2017@mail.ru

Abstract

Introduction: The quality control system for construction and installation operations pursues six objectives: completion on time; completion on budget; compliance with the design documents, codes, and standards; safe operations; improvement of skills and experience; environment protection. **Purpose of the study**: To evaluate reliability of the objectives, correlation between them, and ranking of their priorities within the quality control system for construction and installation operations in Vietnam. **Methods**: The objectives were evaluated by means of a questionnaire survey conducted in Vietnam, using a five-level scale, based on the reliability coefficient α, correlation coefficient *r* and mean value *M*. The sample size was 184. **Results**: According to the results of the questionnaire survey conducted in Vietnam, homogeneity and correlation between the following objectives was observed: compliance with the design documents, codes, and standards; safe operations; improvement of skills and experience; completion on time; completion on budget; environment protection. The objectives were ranked between two groups of respondents by their experience and roles based on the sample size.

Keywords

Quality control, construction, system, construction and installation operations, Vietnam.

Introduction

To consider factors affecting quality of construction operations (Nguyen, Yudina, 2017), a quality control system shall be developed as the contractor influences quality but does not participate in quality control system development (Low, Peh, 1996). As for Vietnam, such quality control system is especially important (Yudina, Nguyen, 2018). Quality control is a part of quality management focused on fulfilling quality requirements (ISO 9000:2015). Quality control primarily deals with issues relating to conformance to the plans and specifications (Low, Ong, 2014). In the field of construction, quality control involves quality assurance with regard to construction of buildings and structures by building contractors with efficient control at all stages of construction product manufacturing (Badyin et al., 2011). In other words, quality requirements represent the objective of the quality control system, which is quality control over construction and installation operations. Any system includes three main components: input, process, and output (Figure 1).

Figure 1. Main components of a system.

Output of the quality control system for construction and installation operations is desired results, or system objectives. Those objectives can include the following: consumer-oriented objective, employee-oriented objective, society-oriented objective, and key operating results (Maslov, Vylgina, 2006). In particular, objectives of the quality control system in construction can include the following: completion on time (G_1); completion on budget (G_2); compliance with the design documents, codes, and standards (G_3); safe operations (G_4); improvement of skills and experience (G_5); environment protection (G_6) (Arditi, Gunaydin, 1997; Cooke, Williams, 2009; Rogalska et al., 2007).

Methods and materials

Polling in the form of a questionnaire was used. The questionnaire prepared by one of the authors of the paper was distributed to employees in the construction industry in Vietnam. Six objectives of the quality control system were graded on a five-level scale (1 — not important, 2 — less important, 3 — important, 4 — very important, 5 — most important). As a result, 184 responds were obtained.

Results and discussion

Evaluating reliability of the objectives

Reliability of the objectives (G_1, G_2, G_3, G_4, G_5, G_6) was evaluated using the Cronbach's alpha coefficient (α) as the coefficient α represents a measure of internal consistency, or homogeneity of a measuring scale (Cronbach, 1951; Nasledov, 2013):

$$\alpha = \frac{k \cdot r}{1 + (k-1) \cdot r}$$

where k is the number of scale points, r is a mean coefficient of correlation between each item and the sum of other items. The value of $\alpha > 0.9$ = excellent; $\alpha > 0.8$ = good; $\alpha > 0.7$ = acceptable; $\alpha > 0.6$ = questionable; $\alpha > 0.5$ = poor; $\alpha < 0.5$ = unacceptable. The obtained value of $\alpha = 0.860$ (Table 1) indicates internal consistency, or homogeneity, of the objectives.

Table 1. Cronbach's alpha coefficient.

No.	Objec-tives	Adjusted correlation between the item and the total score	Cronbach's alpha with the item excluded	Cronbach's alpha
1	G_1	0.686	0.830	0.860
2	G_2	0.685	0.830	
3	G_3	0.490	0.862	
4	G_4	0.723	0.823	
5	G_5	0.697	0.828	
6	G_6	0.631	0.840	

Correlation between the objectives

The correlation between the objectives (G_1, G_2, G_3, G_4, G_5, G_6) was measured using the Pearson correlation coefficient r_{xy}:

$$r_{xy} = \frac{\sum (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum (X_i - \bar{X})^2 (Y_i - \bar{Y})^2}}$$

Here $X_i, Y_i, \bar{X}, \bar{Y}$ are variables' values and their mean.

If $r_{xy} \to 1$, X and Y have a positive linear correlation; if $r_{xy} \to -1$, then X and Y have a negative linear correlation; if $r_{xy} = 0$, then X and Y do not correlate.

The correlation level $|r_{xy}| = 0.3–0.4$ indicates weak correlation, $|r_{xy}| = 0.5–0.75$ – good correlation, $|r_{xy}| = 0.8-0.95$ – very good correlation, $|r_{xy}| = 1$ shows the deterministic nature (Efimov, 2003).

Table 2. Correlation between the objectives.

Objec-tives	G_1	G_2	G_3	G_4	G_5	G_6
G_1	1	0.752	0.357	0.505	0.476	0.510
G_2	0.752	1	0.360	0.556	0.537	0.404
G_3	0.357	0.360	1	0.462	0.429	0.371
G_4	0.505	0.556	0.462	1	0.654	0.595
G_5	0.476	0.537	0.429	0.654	1	0.587
G_6	0.510	0.404	0.371	0.595	0.587	1

The "completion on time" (G_1) and "completion on budget" (G_2) objectives have a strong correlation with the correlation coefficient $|r| = 0.752$ (Table 2), demonstrating that completion on time will allow staying on budget. And vice versa, if the "completion on budget" (G_2) objective is achieved, then the "completion on time" (G_1) objective will be achieved as well.

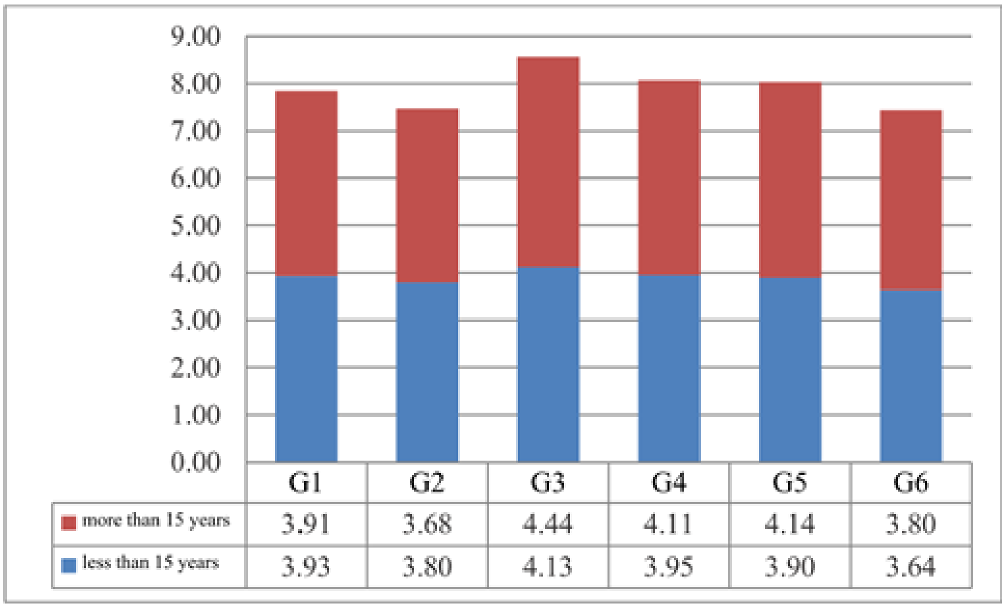

Figure 2. Ranking of the quality control system objectives based on experience of the respondents.

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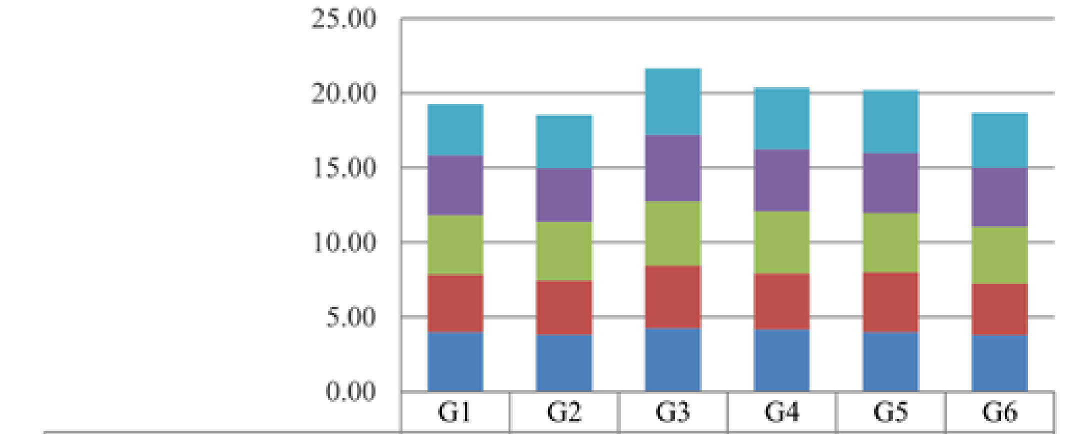

	G1	G2	G3	G4	G5	G6
Engineering supervisor	3.44	3.56	4.44	4.11	4.22	3.67
Engineering contractor	4.04	3.58	4.46	4.19	4.04	3.96
Project manager	3.96	3.94	4.31	4.15	3.98	3.79
Building contractor	3.86	3.63	4.20	3.76	4.00	3.45
Developer/customer	3.97	3.82	4.24	4.15	3.97	3.79

Figure 3. Ranking of the quality control system objectives based on roles of the respondents.

The "compliance with the design documents, codes, and standards" (G_3) objective closely correlates with the "safe operations" (G_4) objective (|r| = 0.462) and the "improvement of skills and experience" (G_5) objective (|r|= 0.429) (Table 2). This correlation shows that if the "compliance with the design documents, codes, and standards" (G_3) objective is achieved, employees will work safely and improve their skills and experience. At the same time, safe operations as well as improved skills and experience will ensure better compliance with the design documents, codes, and standards.

The "safe operations" (G_4) objective correlates with the "improvement of skills and experience" (G5) objective, with the correlation coefficient |r| = 0.654 (Table 2). According to this dependence, if employees work safely, their skills and experience will improve, i.e. qualified personnel will work under safer conditions.

The "environment protection" (G_6) objective correlates with the "safe operations" (G_4) objective (|r| = 0.595) and the "improvement of skills and experience" (G_5) objective (|r| = 0.587) (Table 2). According to this dependence, the "environment protection" (G_6) objective can be achieved only when employees work safely and improve their skills.

Ranking of the objectives

The objectives (G_1, G_2, G_3, G_4, G_5, G_6) were evaluated by five levels, their mean value was calculated as follows:

$$M = \frac{\sum_{i=1}^{N} w_i}{N}$$

where M is the mean value; w_i is the evaluation level (w = 1–5), N is the sample size (N = 184).

The objectives were ranked using three criteria: experience of the respondents, roles of the respondents, and total score. 52.2% respondents (n = 96) had more than 15 years of experience, and 47.8% (n = 88) had less than 15 years of experience. Both groups agree that "compliance with the design documents, codes, and standards" (G_3) is the primary objective of the quality control system for construction and installation operations. In the meantime, such quality control system has a minor effect on the "completion on budget" (G_2) and "environment protection" (G_6) objectives (Figure 2).

The respondents had the following roles: building contractor (27.72%), project manager (26.09%), developer/customer (18.48%), engineering contractor (14.13%) and engineering supervisor (4.89%) (Table 3).

Table 3. Roles of respondents.

No.	Role	Number of respondents, n	Per cent, %	Cumulative %
1	Building contractor	51	27.72	27.72
2	Project manager	48	26.09	53.80
3	Developer/customer	34	18.48	72.28
4	Engineering contractor	26	14.13	86.41
5	Engineering supervisor	9	4.89	91.30
6	Other	16	8.70	100.0
	Total (N)	184	100.0	

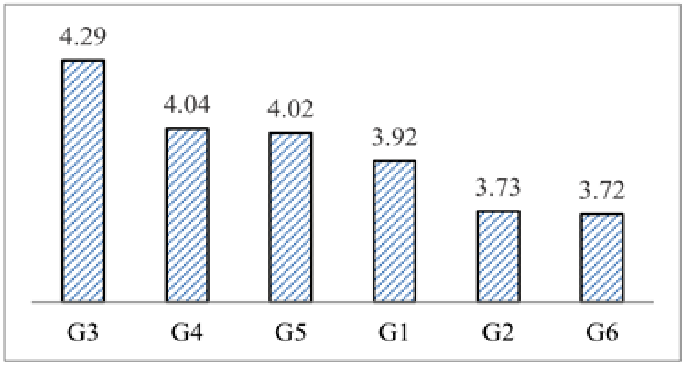

Figure 4. Ranking of the objectives in the quality control system for construction and installation operations based on the data of the questionnaire survey conducted in Vietnam.

The objectives were evaluated in the entire sample size (N = 184). The hierarchy of the quality control system objectives includes: compliance with the design documents, codes, and standards (G_3); safe operations (G_4); improvement of skills and experience (G_5); completion on time (G_1); completion on budget (G_2); environment protection (G_6) (Figure 4).

Conclusions

Rankings of the objectives by experience, by roles and in the entire sample size give similar results. Assurance of compliance with the design documents, codes, and standards represents the primary objective of the quality control system for construction and installation operations in Vietnam. This objective correlates with the "safe operations" (G_4) and the "improvement of skills and experience" (G_5) objectives. Therefore, to achieve it, it is necessary to provide safe labor conditions and have plans for skills improvement in place. This objective can meet the requirements of consumers (Nguyen, Yudina, 2017) and employees in accordance with the quality control mechanism in the construction industry in Vietnam (Yudina, Nguyen, 2018). Its achievement provides a basis for achievement of quality in construction and installation operations at a construction facility in Vietnam.

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ЦЕЛИ СИСТЕМЫ КОНТРОЛЯ КАЧЕСТВА СТРОИТЕЛЬНО-МОНТАЖНЫХ РАБОТ В УСЛОВИЯХ ВЬЕТНАМА

Тхай Хиеп Нгуен[1], Антонина Федоровна Юдина[2]

[1,2] Санкт-Петербургский государственный архитектурно-строительный университет
2-ая Красноармейская ул., 4, г. Санкт-Петербург, Россия

[2] Автор, ответственный за переписку: yudinaantonina2017@mail.ru

Аннотация

Введение: Система контроля качества строительно-монтажных работ (СМР) состоит из 6 целей: завершение в срок, завершение в рамках бюджета, соответствие проектным документам, кодексу, стандартам, работа в безопасных условиях, совершенствование своих навыков и опыта, а также охрана окружающей среды. **Цель исследования: о**ценить надежность целей, корреляцию между целями и ранжирование приоритетов этих целей в системе контроля качества СМР в условиях Вьетнама. **Методы:** Цели оценивались по пятиуровневой шкале с помощью анкетирования, проводимого во Вьетнаме, с размером выборки 184, на основе коэффициента надежности α, коэффициента корреляции r и среднее значение M. **Результаты:** На основании результатов проведенного анкетирования во Вьетнаме, показана однородность и корреляция между следующими целями: соответствие проектным документам, кодексу, стандартам, работа в безопасных условиях, усовершенствование своих навыков и опыта, завершение в срок, завершение в рамках бюджета, охрана окружающей среды. Цели ранжировались между двумя группами участников опроса по опыту и роли на основе размера выборки.

Ключевые слова

Контроль качества, строительство, строительно-монтажные работы, Вьетнам.

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Urban planning

PATTERN METHOD IN URBAN STUDIES AND PRACTICES

Anton Gashenko

Novosibirsk State University of Architecture, Design and Arts
Krasny prospect, 38, Novosibirsk, Russia

Email: antongashenko@yandex.ru

Abstract

Introduction: The paper addresses an issue of describing templating in the urban environment. It also declares an approach to studying and designing urban space using patterns — spatial prototypes of the area. **The purpose of the study** is to provide insight into the pattern method applied in urban studies and practices. **Methods**: Using the theory of C. Alexander, the authors model the concept of pattern in urban planning, describe the process of urban environment development based on spatial "templates" of its formation. **Results**: City development is based on localization of design models for area planning or natural landscape-shaping mechanisms. Such design models and natural mechanisms are called patterns. Patterns are imprinted in the city fabric as locally coherent urban-planning formations — elementary urban units. Properties of patterns (integrity, limitation and repeatability) are listed. Principles of their use in studying urban-planning structures, preserving the genetic code of local areas, and modeling new spatial forms using urban-planning strategies and regulations are described.

Keywords

Pattern, urban morphology, integrity, development, landscape.

Introduction

The information paradigm of the late 20th – early 21st centuries required the use of automation and optimization tools in urban planning. Such tools allowed operating with big data and simplifying resource-intensive procedures in studies and design.

In the 20th century, urban design was mainly based on manual control. In fact, the pre-computer technology of urban-planning documentation development contributed to that. Automated design systems (and later — geo-information systems) placed stringent requirements for data structuring, classification of basic design processes and urban environments.

At the time, in world science, theories pointing at repetition, copying of real (physical) objects and processes appeared. A theory of patterns (where patterns are actually sustainable models of individual or group behavior), which first emerged in social psychology and biology, became one of those. In the course of IT development, programmers started to use the "pattern" term to designate design patterns (Leitner, 2015b).

In 1977, British architect Christopher Alexander in the book "A pattern language: towns, buildings, construction" (Alexander et al., 1977) identified more than 250 typical situations in urban design space planning, characterized by stereotypical problems and solutions — from park benches to a "community of 7000". Alexander called such situations "patterns". He also described their features and ways of resolution. His idea was rather pragmatic: typification and generalization of common phenomena allow saving the means to resolve them, using ready-made developments instead of searching for new solutions.

In the Russian urbanology, the phenomenon of patterns was noted by M. V. Shubenkov and N. N. Shamarov (2008). They referred to those as "domain models" — prototypes of planning and development, spatial "templates". However, as early as in 1975, A.G. Rappaport examined in detail the phenomenon of prototypes in engineering. His research relates to criticism of the prototype approach and its replacement with the "design methodology" as a new (at the time) approach to solving design problems. The pattern method we declare remains relevant for two reasons. First, despite the fact that designing with prototypes was criticized more than 50 years ago, this approach has not been overcome yet and remains a stable form of professional activity. Even in the concept of C. Alexander, declaring the need for a "completely new design organization, which is not based on samples or prototypes," according to A.G. Rappaport, "traditional patterns of the "form" (elements of particular prototypes) play a significant constructive role” (Rappaport, 1975). Second, although the pattern method exploits prototypes as spatial-historical phenomena, it is not limited to their reproduction, using them mainly as an analytical tool, which will be discussed later.

The principle of "patterns" can be applied to the classification of urban environments. It is noted that the formation of urban space occurs in “portions”, or plots, and each of those develops according to a stereotypical “template” — pattern.

These patterns appear as spatial-historical precedents (phenomena of urban development), being caused by social and economic, technological and other factors. Each new major phenomenon in culture gives rise to a new stereotypical method of spatial organization (Bystrova, 2011). Urban-planning evolution is, in fact, evolution of stereotypical methods of spatial organization, replacing each other.

Patterns that are stable over time become some sort of spatial archetypes. Individual housing is one of the most vivid examples of an evolving pattern preserving its archetypical nature.

Patterns represent concepts of area development or natural mechanisms of spatial growth. Each such mechanism is reflected in the urban space more than once, becoming a stereotypical pattern.

Moreover, perception of the urban environment establishes the “stereotypical” nature of the spatial structure (Filanova, Nikonov, 2016) and it is sensitive to violations of the integrity and deformation of the original patterns (with the phenomenon of infill construction being one of the most typical cases of such deformations).

Thus, the pattern structure of space is an objective phenomenon, based on which we can formulate research and design principles of area planning.

These observations lead us to the following **hypothesis**. Optimization of urban planning is possible due to: 1) identifying spatial and planning stereotypes (patterns) at the stage of city research; 2) managing development of such stereotypical units; 3) creating new patterns. These three operations can be combined into the pattern method.

Thus, the subject of the study is essence of pattern method application in urban studies and design.

The purposes of the study are as follows:

1) to describe the concept of pattern, its essence and properties.

2) to describe pattern method application in classification of city’s spatial environments;

3) to suggest using the pattern method in strategies of local areas’ spatial development;

4) to specify the basis for designing new patterns.

Methods

In the present paper, methods of theoretical modeling and concept definition are used.

Results and discussion

Essence of the pattern phenomenon and its properties

According to the results of author's studies of the Novosibirsk spatial structure (Gashenko, 2016), the urban fabric is based on patterns — spatial templates of buildings or landscapes. Pattern is a spatial and historical stereotype reflected in the urban structure in the form of an incarnation series (imprints) — locally coherent urban-planning formations or urban units (Figure 1). Each pattern has its own typical idea, concept, or natural mechanism of spatial formation, which translates into the corresponding urban units. It manifests itself in numerous characteristics: functional, architectural and planning, stylistic (environmental), and semantic.

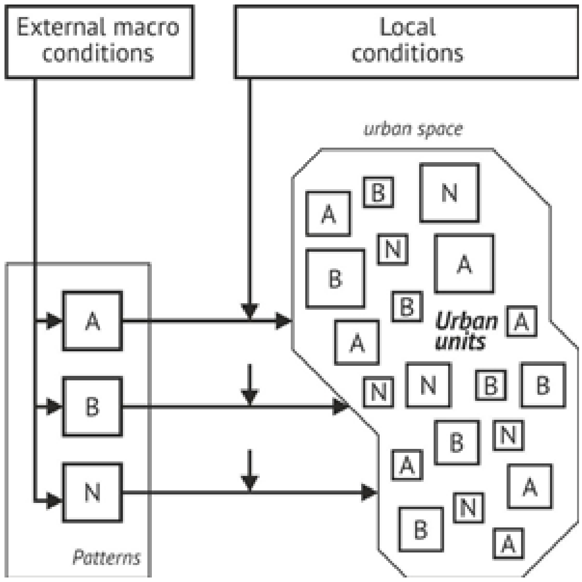

Figure 1. Pattern structure of space.

A city block serves as a pattern example. It is the most prevalent and at the same time the most multivariate spatial and planning stereotype. There are numerous variants of city blocks, but they all have a single basic planning scheme. In the city block pattern, planning characteristics of the space mainly manifest themselves, and functional, architectural, as well as figurative and semantic characteristics may differ significantly in different manifestations. As for the micro-district pattern, all its characteristics are more pronounced, but in terms of planning it also has many different interpretations. Public and mixed housing areas almost entirely depend on the function and semantics given a wide variety of planning forms.

This suggests that the urban morphology is not reduced to mere development morphotypes, but rather described by a set of the listed characteristics with different ratios of their manifestation. We can distinguish architectural, stylistic, social, semantic and functional features of the environment morphological integrity.

Each pattern is a phenomenon of urban evolution with unique features and parameters. Their study is important in terms of inheritance of urban morphology samples and its translation into urban planning documents. Preservation of environmental samples through spatial

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Figure 2. Guangzhou districts.

prototypes (patterns) allows reproducing the “genetic code” of an area.

Patterns also have several a priori properties that define their essence.

Integrity of anthropogenic patterns is predetermined by the project-based method of their formation. Every idea strives for integrity and completeness. It is natural for a designer to make a completed work within the originally specified boundaries. The urban environment based on this principle represents a patchwork of scattered fragments, mechanically stitched along the lines of the street-and-road network. Therefore, linking of conflicting, locally coherent formations (elementary urban units) based on various patterns, and filling in the gaps of the urban fabric are carried out using non-standard, unique solutions. Integrity of natural patterns (landscapes) is predetermined genetically, but here we can also observe cases of spatial deformations.

Integrity is related to another pattern property — **limitation**, i.e. territorial certainty. Patterns are localized within rigid boundaries as separate integral “portions”, forming the mosaic of the urban fabric. In their pure form, patterns manifest, for example, in the formation of micro-district structures disregarding the urban context. Direct

Figure 3. Repetition of residential groups in the Snegiri micro-district in Novosibirsk.

Figure 4. Identification of hypothetical locally coherent urban-planning formations created by the corresponding patterns, and their limitations.

application of such spatial patterns is a phenomenon of the modernist culture. This can be observed in works of students, when a complete but self-contained formation is implemented within the specified boundaries. Obtrusiveness of primitive patterns characterizes the modern development in Chinese residential areas (Figure 2). Thus, adaptation of patterns to an uneven urban structure without integrity loss can be considered the art of urban planning.

Repeatability is the main pattern property distinguishing the pattern from individual and unique design solutions. It is the whole point of its template and prototype structure. However, repeatability is conditional, and the degree of conditionality depends on the physical size of the urban-planning structure set by the pattern. On the one hand, replication of ribbon residential development groups in micro-districts is almost identical in all pattern properties. On the other hand, templating of urban areas is very weak despite the fact that in modernist Soviet cities it was a standard. This can serve as an evidence of the uneven and multi-layered urban structure. In fact, difficulties of studying the phenomenon under consideration are associated with that.

Pattern identification and studies

As it was mentioned, patterns are reflected (displayed, imprinted) in the form of a series of incarnations — locally coherent urban-planning formations. A method to analyze and describe such local units is proposed, where the identification stage is based on the pattern theory and involves the following.

At the *identification stage*, a fragment of the urban space is associated with the locally coherent urban-planning formation, where the pattern (or patterns), that formed it, is recognized in the environment area (Figure 4).

For these purposes, a historical and genetic analysis is performed, revealing the spatial and temporal dynamics of the evolution in the given area (Kubetskaya, Kudryavtseva, 2017). The analysis allows identifying "epoch footprints" and restoring the original picture of the urban environment development. This is especially important in case of multiple layers of different patterns (development or landscape templates). At this stage, all possible sources are used that indicate the element character of the urban space: data of cartographic databases, materials on urban toponymy, historical descriptions (essays, articles on regional studies, sources of oral history).

The search for morphology sources regarding the local area is necessary for reconstruction (regeneration) of its original integrity. Studies are conducted within the boundaries of the existing elements of the planning structure — micro-districts, city blocks and other elements fixed by red lines. Depending on the complexity of the urban-planning situation as well as spatial and temporal dynamics within the same element of the planning structure, up to several hypothetical locally coherent urban-planning formations, created by different patterns, can be identified[1]. In such case, conditional boundaries of spatial environments become boundaries of urban units.

At this stage, the hierarchical structure of a locally coherent urban-planning formation can be revealed, where within the same unit (e.g. a micro-district), smaller units are identified, such as residential groups, school and kindergarten areas, as well as public hubs. Fractality of patterns and the urban environment formed on their basis is one of the interesting spatial phenomena. The hierarchy mentioned is used in urban studies in design concepts of the social infrastructure or in descriptions of cognitive levels of spatial environments as macro-, mezzo- and micro-spaces (Krasheninnikov, 2015).

Management

To regulate development of an architectural and historical environment, it is advisable to use the pattern method, the essence of which is to apply spatial development strategies to areas formed by particular

1 This is typical, for example, for central historical districts subject to multiple transformations of the spatial environment.

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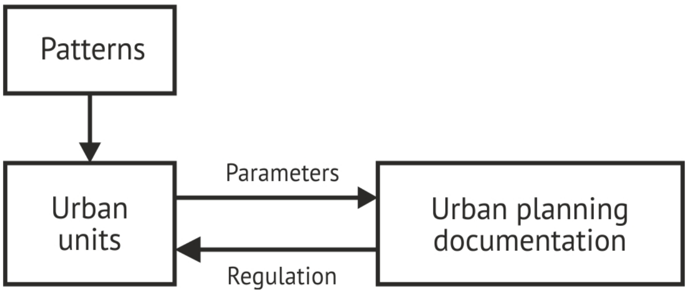

Figure 5. Mechanism of pattern reflection and translation of urban morphology.

patterns, leading to their transformation or preservation. In this case, those strategies serve as patterns — typical ways of solving the problem in accordance with the objective.

For instance, when dealing with almost dilapidated quarters of the 1940s–1950s, constructed near factories, it is possible to apply the following pattern strategies:

a) redevelopment — development of built-up areas with demolition and new construction without morphotype preservation. A particular case of such redevelopment — development of an area with dilapidated or dangerous buildings — is established in the town-planning code in the form of a special law mechanism (Trutnev et al., 2006);

b) modernization — evolutionary development of an area with nuanced changes in morphotype characteristics;

c) contextual regeneration — comprehensive reconstruction of an area (Brownfield) with new construction according to a historical or similar morphotype.

In the second and third cases, we need to know peculiarities of the initial pattern, e.g. its architectural and urban-planning morphology, which will be reflected in further development of the area.

Strategies for spatial development of an area (at the stage of spatial planning) and urban-planning regulations (at the stage of urban development zoning) represent a way to establish a particular pattern.

New patterns

Design of new urbanized forms for mass use is, in fact, formation of new patterns. it is performed during urban-planning modeling without reference to a specific situation. That way the micro-district concept was formed. The process of pattern designing is accompanied by:

- calculation of typical technical and economic indicators that can be used in predicting development of the area formed by this pattern;
- visualization of a “sample” of the urban development environment for the purpose of public presentation.

Experimental design, architectural competitions for development of new principles for construction organization can also be considered as creation of new patterns. As for the Russian urban planning, the methodology of such work has not been studied sufficiently despite the long-standing problematization. This points to the fact that methods of designing new urban-planning patterns represent one of the current trends in modern science (Ptichnikova, Antyufeev, 2014).

Conclusion

The performed study allows drawing several conclusions. It has been confirmed that the urban environment is based on patterns — spatial and planning prototypes of buildings or landscapes (or “templates” of spatial formation). Patterns a priori represent holistic structures, therefore, their “imprints” in the city fabric can be called locally coherent urban-planning formations. In order to identify such territorial elements, an imprint is compared with the generating pattern.

To preserve the genetic code of a local territory, or transform it, laws and principles of spatial pattern formation are used in spatial strategies and urban-planning regulations. Formation of new stereotypical forms of environment organization is, in essence, creation of new patterns.

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МЕТОД ПАТТЕРНОВ В ГРАДОСТРОИТЕЛЬНЫХ ИССЛЕДОВАНИЯХ И ПРОЕКТИРОВАНИИ

Антон Евгеньевич Гашенко

Новосибирский государственный университет архитектуры, дизайна и искусств
Красный пр., 38, Новосибирск, Россия

Email: antongashenko@yandex.ru

Аннотация

Введение: В статье поднимается вопрос описания шаблонности городской среды. Декларируется подход к исследованию и проектированию городского пространства посредством паттернов – пространственных прототипов территории. **Цель исследования:** раскрыть сущность метода паттернов в градостроительных исследованиях и проектировании. **Методы:** Опираясь на теорию Кристофера Александера, моделируется понятие паттерна в градостроительстве, раскрывается процесс развития городской среды на основе пространственных “шаблонов” её формирования. **Результаты:** Выявлено, что развитие города происходит путем локализации проектных моделей организации территории или естественных природных механизмов формирования ландшафта. Такие проектные модели и природные механизмы названы паттернами. Паттерны отпечатываются на теле города в виде локально-целостных градостроительных образований — элементарных планировочных единиц. Приводятся свойства паттернов (целостность, ограниченность и повторяемость). Описываются принципы их использования в исследованиях градостроительных структур, сохранении генетического кода локальных территорий и моделировании новых пространственных форм при помощи градостроительных стратегий и градостроительного регламента.

Ключевые слова
Паттерн, морфология города, целостность, застройка, ландшафт.

MARINE FACADE, WESTERN HIGH-SPEED DIAMETER AND VASILYEVSKY ISLAND AS A PART OF THE SAINT PETERSBURG HISTORICAL CENTER

Leonid Lavrov[1], Elena Molotkova[2]

[1,2] St. Petersburg State University of Architecture and Civil Engineering
Vtoraja Krasnoarmejskaja st., 4, St. Petersburg, Russia

[1] Corresponding author: leonid.lavrov@gmail.com

Abstract

Introduction: Using the example of the Maritime Facade project being implemented, a gap is revealed between the strategic installations of the St. Petersburg development, defined by the city planning system and enshrined in the master plan of the city, and the real transformation of the architectural environment of Vasilyevsky Island. **Purpose of the study:** Identify the most significant omissions made during the implementation and repeated adjustments of the original concept. **Methods:** A comparative analysis of the key provisions of the initial concept and indicators of the currently formed urban environment. **Results:** An underestimation of a radical change in the urban development situation in the city center caused by the laying of a high-speed highway on the western part of Vasilyevsky Island was revealed. peripheral territories, does not allow it to solve the problems of the development of a highly urbanized environment arising in this process. The facts are outlined, showing how a consistent adjustment of the original concept created the basis for the formation of a peripheral-type residential living quarters in the unique coastal zone and the laying of a suburban-type autobahn. The list of measures that could reduce the associated negative impact on residential areas is defined. It is noted that the negative experience of the project "Marine Facade" in St. Petersburg should be taken into account in the urban planning practice of other metropolises of our country.

Keywords

Saint Petersburg architecture, urban planning, water areas and coastal territories, city center and transport framework.

Introduction

The Saint Petersburg coat of arms contains images of two anchors – a sea one and a river one. This eloquently reflects the specifics of city development. Although Saint Petersburg is the largest Russian sea port, its development on the banks of Neva, where the most significant historical buildings were erected, continued for centuries. Residential areas approached the shore of Markizova Luzha (Neva Bay of the Gulf of Finland) as late as in the 20th century. In 2011, when the construction of the flood wall with a highway was completed, the Saint Petersburg administrative borders covered the area of 1,403 km^2. Currently, the urban area of various modifications comprises all shores of Neva Bay. The transportation network including a belt highway provides a perimetral bypass around the water area. Markizova Luzha[1] became an inland water body of the city both in terms of hydrology (https://asninfo.ru/interviews/349-yuriy-shevchuk-na-vopros-o-tselesoobraznosti-namyva-otveta-net-ni-u-biznesa-ni-u-vlasti) as well as functional and planning indicators (Figure 1).

The eastern part of the city is the most urbanized. The historical center of Saint Petersburg is located there (the central districts of the city are colored with red in Figure 1). It is clear that the territories are divided by the Neva delta branches. That is why a system of bridges interconnecting the districts is of high importance. The main transportation lines of Saint Petersburg passed through the city center, as shown in Figure 1 (they are highlighted in white). Since such system resulted in overload of the city core and elongation of transportation lines, options to lay additional transport corridors to bypass the historical center were developed. In 1996, the concept of the Western High-Speed Diameter (WHSD) was approved. It suggested to connect the northern and southern parts of Saint Petersburg with a new highway along the western shore of Vasilyevsky Island (https://www.nch-spb.com/o-proekte/istoriya-proekta/). This route is shown in a blue dotted line in Figure 1. In 2002, it was proposed to create a complex for sea cruise ships near the western shore of the island, and the government ordered to start the construction of the port in 2005. Those decisions had a strategic significance for city urban-planning development. They predetermined the current reconstruction of Vasilyevsky Island and will probably affect further evolution of the Saint Petersburg center.

[1] Neva Bay (Markizova Luzha) is the eastern part of the Gulf of Finland. The line of protective structures can be considered its current border. The length of Neva Bay is 21 km, the widest place is 15 km, the average depth is about 3.0 m, the area of the water plane is 380 km^2.

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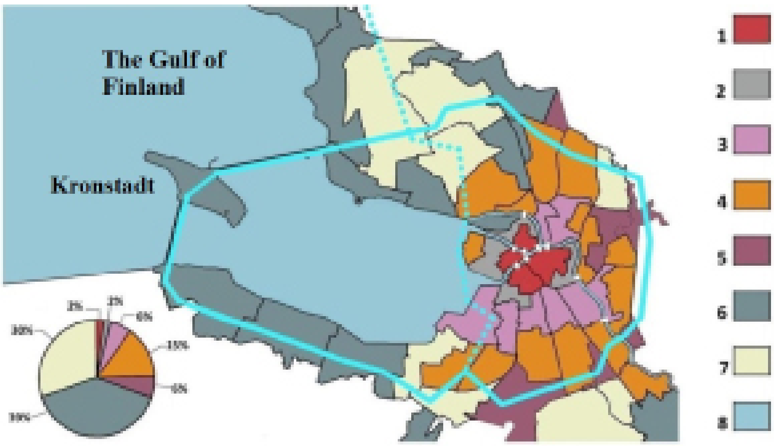

Figure 1. Layout of Saint Petersburg districts around the Neva Bay water area (as of the beginning of the 2000s.
1 — core of the city center, 2 — industrial and residential areas of the central districts, 3 — industrial and residential areas adjacent to the central districts, 4 — belt of large-scale residential development, 5 — external industrial areas, 6 — suburban territories, 7 — undeveloped forests and agricultural territories, 8 — water areas

Marine Facade of the 21st century

In 2007, the Government of Saint Petersburg declared its intentions to construct a hydraulic fill area of more than 400 ha at the western shore of Vasilyevsky Island in order to "develop the territories, build the Marine Facade and increase attractiveness of the city for tourists". It was stated that 33 ha were intended for the marine passenger terminal. The rest of the territories were allocated for offices, hotels, residential houses, exhibitions and shopping malls. A new waterfront of Saint Petersburg including a business center with high dominants was the intended result. As the construction of the Western High-Speed Diameter was underway at the time, it was decided that its central part should be laid through a hydraulic fill area (https://www.spb-guide.ru/page_18965.htm).

Experts thought that buildings with the total area of up to 4 mln m^2 could be built in the hydraulic fill territories,

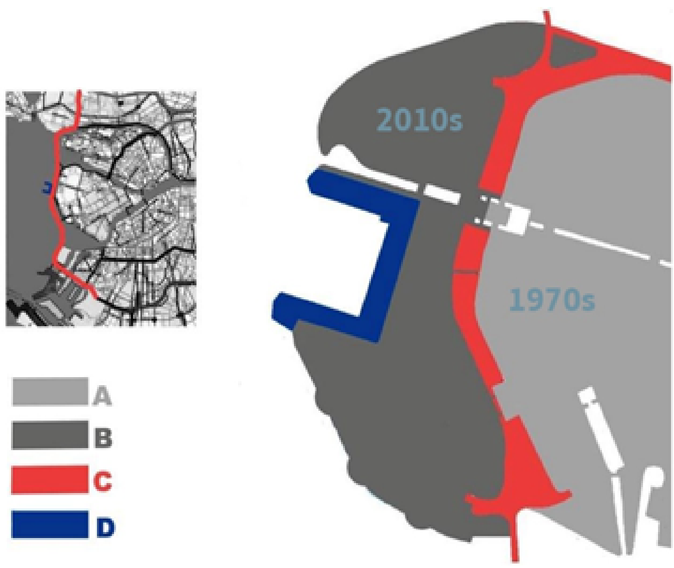

Figure 2. Top left — layout of transportation facilities in the Gulf of Finland water area
A — the territory established by the 1970s, B — the residential area in the hydraulic fill territories constructed in the 2010s, C — the highway with a sanitary protection zone, D — the port territory.

and the total cost of the project would be about USD 13 bln (https://www.novostroy-spb.ru/statyi/namjyvnjye_territorii_chto). In 2007, a project of hydraulic fill area development was approved. It embraced a part of the city with the total area of 476 ha (almost 30 ha of them were water areas, and 36 ha — areas of the passenger port and riverside wharves). 228 ha were intended for the street-and-road network (including the WHSD). 218 ha were supposed to be used for buildings. The share of residential areas (85.4 ha in total) was comparable to the territory of public and business facilities.

Subsequent adjustments introduced significant changes to the initial designs. However, the basic framework of the layout remained unchanged:

- the port area is prominent due to its size and accurate planning;

- the wide highway with the sanitary protection zone cuts off new territories from the part of the island that existed before;

- the outlines of the residential area remind of a dumbbell (offices in the north, residential buildings in the south, and a rather narrow connecting area between them) (Figure 2).

Since then, a bit more than 10 years passed. Hydraulic filling has been completed by 67% (https://www.dp.ru/a/2018/10/24/Otmitie_gektari), and the design documentation covers the whole area. Some conclusions can be made at this stage. Figures indicate successful development of the sea port and highway, but changes in the residential area became the source of numerous negative comments. They concern both the hydraulic fill territories as well as the development on Vasilyevsky Island that existed before.

Results. Marine Facade and WHSD

1. In 2008, the marine passenger terminal named Marine Facade was commissioned. Since then, the cruise passenger traffic increased here more than twice (https://www.gov.spb.ru/press/governor/127816/). In 2017, 247 cruiser ships and 2 ferry boats berthed there. 562,000

passengers arrived. It is 23% more than in 2016. The Russian Government ordered to use this port for cargo operations (https://regnum.ru/news/2398952.html).

2. In December 2016, traffic in the central part of the Western High-Speed Diameter (WHSD) in the hydraulic fill area on Vasilyevsky Island was started. Separated sections of the highway became a single system, and the traffic of vehicles racing at the speed of more than 100 km/h increased from 120,000 vehicles/day to 200,000 vehicles/day (https://www.fiesta.city/spb/news/tsifra-dnya-200-000-mashin-proezzhaet-po-tsentralnomu-uchastku-zsd/). 250,000–300,000 drivers use the toll road daily. In 2018, the traffic on the WHSD was 88 mln transactions, which is 10% more as compared to the previous year (http://www.spb.aif.ru/society/people/avtomobilisty_oplatili_proezd_po_zsd_v_peterburge_bolee_80_mln_raz_za_god).

Results. Residential area

A significant part of the territory has been hydraulically filled in the residential area. The first residential complex has been built already. Design documentation has been developed and adjusted. It determines the structure of the entire new part of Vasilyevsky Island. However, the ambitious goals of 2005 are often not mentioned.

• Aesthetics and distinctiveness of the buildings. The architectural image of the constructed development lacks individuality and reminds of a typical peripheral dormitory district. There are no expressive dominants. The Chief Architect of the city has to note that not the Marine Facade is built in the hydraulic fill area, "but just residential buildings that can be seen from the seaward". Journalists competing in wittiness predict that another uniform "dormitory district" like "Shushary-2"(https://www.fontanka.ru/2017/11/08/105/) or "Murino-2" can appear here (https://gre4ark.livejournal.com/468623.html).

We can see no prospect of any significant buildings that could become new symbols of the city and make Saint Petersburg more attractive for tourists, like those facilities that are currently built in many reconstructed coastal areas[2]. The concept of development in the hydraulic fill area in Saint Petersburg, modified in 2014, does not feature any "significant, structural, anchor facilities that, according to representatives of the property management company, are not really interesting in a commercial sense, but "can revitalize the whole area" (Arkhipov, 2007). Right now, there are plans in place for a standard set of micro-district infrastructure elements, as well as areas for a children's hospital, substation and boiler house, yacht club with a marina for small ships. City-wide interests have not been taken into account. Only a tree lawn is made in the hydraulic fill area as a magnet for the city folk.

The attractiveness of the new district for tourists also remains doubtful.

• Environment: the commissioning of the central part of the WHSD having a particular impact on the environment (noise, exhaust gases, grogs and dust from tires and asphalt, finely-dispersed particles) came as a shock for the population of the western part of Vasilyevsky Island.

The highway section laid in the hydraulic fill area was commissioned on December 4, 2016. A petition of the locals complaining about the noise was submitted as early as on December 5, 2016 (https://nevnov.ru/511321-zhiteli-namyva-na-vasilevskom-nedovolny-shumom-zsd). The prediction of specialists proved to be true: the area along the former Morskaya Embankment became one of the least favorable parts of the city in terms of environment (https://spbguru.ru/advice/105-samye-shumnye-rajony-sankt-peterburga).

Official information on the changes in the environmental status of this area is unavailable, but the data on the Saint Petersburg belt highway (where the "noise pollution" spreads to 320–1,100 meters to the both sides of the traffic way) can be treated as a precedent (https://saint-petersburg.ru/m/society/bespalov/360590/). The situation concerning the WHSD remains stringent, and the protests do not fade away. Both residents of the blocks adjacent to the WHSD from the east and new tenants participate in the protests.

The list of other claims of new tenants, concerning the quality of the living environment, is rather extensive. The issues are related to the lack of local passways and utility facilities (https://moika78.ru/news/2018-10-17/48829-namyv-razdora--goryachiey-tochki-novykh-territoriy-peterburga/). It should be taken into account that the discontent is currently mainly caused by the fact that the works have not been completed yet.

It is hoped that the hardships of the initial stage of development will be resolved: all planned buildings will be completed, local passways will be surfaced, the infrastructure prescribed by regulations will be created, and an extra junction will be made on the WHSD (according to the Government of Saint Petersburg, "someone will have to be squeezed. And they will hardly like that" (https://www.spb.kp.ru/daily/26582.4/3597223/). Will the environment created due to these efforts be flawless? It is clear that there are no grounds for the positive answer. The hydraulic fill areas and the nature of the emerging development resulted in structural changes that affected the entire Vasilyevsky Island.

Vasilyevsky Island to the east from the WHSD

Western part of Vasilyevsky Island before the second hydraulic filling

The first steps to domesticate the western territory were made as early as during Peter the Great's reign: Galernaya Harbor with a marine settlement on the shore of the Gulf of Finland appeared simultaneously with the Kunstkamera and Twelve Collegia. However, these areas were acknowledged as a part of the city in 1808 at the earliest, when the Stock Exchange colonnade rose above the Neva waters in the eastern part of Vasilyevsky Island. For a long time, the harbor remained a peripheral

[2] High priority is assigned to the individuality and dignified appearance of the new coastal complexes, and significant funds are allocated for landmarks. Such buildings as the Sydney Opera House, Oslo Opera House, Hamburg Elbphilharmonie, Film Institute, Nemo, Music House in Amsterdam, new theaters and the Black Diamond Library in Copenhagen, etc. contribute to a city's renewed image

Figure 3. Development of the territory of Vasilyevsky Island as a part of the historical center (yellow lines show transportation routes established by the 18th–beginning of the 20th centuries, and blue lines indicate new highways. The letter M designates the sea port).

settlement and was separated from the main part of the island by a large forested swamp — Smolenskoye Field. The harbor also had features of undeveloped suburbs for a good while. At the turn of the 19th–20th centuries, factory facilities and massive tenement buildings started to appear, but many dwellers of the harbor continued to use water from the Shkiperskiy Canal flowing from a dump located nearby. The rate of urbanization was slow. Even as late as in the 1950s, a large littered lowland was situated on the shore. Its reed wasteland was filled with piled-up water from autumn storms. In some places, there were temporary structures built by fishermen, and the wind filled the air with the odors of a feeder pig farm situated nearby on the bank of the Smolenka River. Project designs of the 1930s–1950s were aimed at extensive development of these territories, with subsequent formation of green areas and construction of low-rise buildings.

Urban-planning transformations started in the 1960s, when the era of large-scale low-income housing development dawned in the USSR. In Leningrad, large peripheral areas outside the industrial belt (highlighted in grey in Figure 1) were allocated for "conveyor" housebuilding according to standard designs. Products of local housebuilding factories started to fill the suburbs in Kupchino, Vesely Settlement, Rzhevka–Porokhovye — in total, 15% of the entire area of the modern city (highlighted in brown in Figure 1).

Paradoxically, but in these conditions, when architecture was within the rigid framework of utilitarian practicability, an ambitious idea to "create a waterfront worthy of Leningrad in the north-western and western parts of Vasilyevsky Island" took on. This concept was developed by Leningrad architects in the late 1950s (Naumov, 1960). Architectural processes that started on Vasilyevsky Island during these years are shown in Figure 3. The area of the historical center of the city under UNESCO protection is highlighted in color (http://www.spb.aif.ru/dontknows/1196561). It comprises the Admiralty Part (A), Petrograd Side (P) and the east of Vasilyevsky Island (B). In the late 1950s, the vacant land in the north-west of Vasilyevsky Island (NW) was considered as a site where residential areas could be located. Those areas were intended to solve the housing problem of employees of the nearby shipbuilding facility. Unlike other territories assigned at the time for large-scale construction and located near industrial areas and suburban vegetable gardens, this part of the island was between the shore of the gulf and the historical core of the city. The exclusive potential of that architectural situation did not go unnoticed, and the leading architects of the city (V.A. Kamensky, A.I. Naumov) and even the USSR (N.V. Baranov) took interest in it.

Architecture was financed "by a leftover principle", as it was customary in the conditions of the planned economy. A design and construction method, as per which Lenproyekt architectural bureaus were essentially a part of a housebuilding conveyor that filled peripheral districts with unified buildings based on standard designs, was common for those years. The specifics of the territory in the north-west of Vasilyevsky Island required adequate architectural solutions, and the status of an experimental project was assigned to the new work. This improved funding a bit and, which is more important, allowed shifting away from the principles of large-scale production of residential areas, and aiming the efforts of the architects to a search for original architectural and urban-planning solutions designed to take into account the uniqueness of the environment, use the potential of this place and shape a new impressive city district. An architecture bureau headed by S.I. Evdokimov was assigned to find a comprehensive solution of those tasks. The bureau had to not only create the design, but also coordinate the activities of organizations participating in the development of new territories.

They had to perform hydraulic filling and raise the level of the flooded territory to prepare the required construction site. The canal between Dekabristov Island and Volny

Figure 4. Creation of the Leningrad waterfront in the 1970s: - in the center – a development layout; on the right (a) — a photo of the territory along the Smolenka River; on the left (c) — a model of the marine passenger terminal and an option of a planned hotel.

Island was filled up. The new shore came forward into the gulf for hundreds of meters, which resulted in about 350 ha intended for housebuilding (http://gorod.spb.ru/articles/1699) (these territories are marked as NW in Figure 3).

A concept that fit into the traditions of Saint Petersburg shaping under the conditions of limited funding was accepted. The objective of Chief Architect of Leningrad V.A. Kamensky was taken into account: "...building new districts, we need to consider the principles of compositions in brilliant architectural ensembles of the old Saint Petersburg <...> development and improvement of those traditions is the only proper method of building new districts" (Ovcharenko, 2016). In the city known as the "Northern Venice", great value was placed on interaction of the buildings with the water areas. Along the waterline, a recreational line was suggested, along the red line — a dense front of residential complexes. There were few design accents, and they featured development of an open public space protruding deep into the shoreline (Figure 4). The bed of the Smolenka River was turned to the Gulf of Finland and enframed with granite blocks. The buildings on the embankment formed a wide visual corridor that stretched for almost a kilometer. The marine horizon could be seen from that corridor (Figure 4a). Later on, Marine Cascade and Marine Facade residential areas on the coastline of the Gulf of Finland adjoined the area.

A complex with the Pribaltiyskaya hotel became another landmark (Figure 4b). Here, in the architectural forms of the 1970s, a parallel with a classic complex on the Strelka (Spit) of Vasilyevsky Island was intended to be made. Classic methods of the urban-planning art were applied using modern stylistics(http://novayagazeta.spb.ru/articles/9262/):

- the architectural ensemble connected large open spaces on the main land and the gulf; it had a clear axial symmetry;
- the main facilities were raised on a high granite pedestal, and large stairs led to a vast embankment.

A congress and exhibition center started to develop dynamically near the historical Galernaya Harbor, at the outlet of Bolshoy Prospekt to the sea. Small shopping

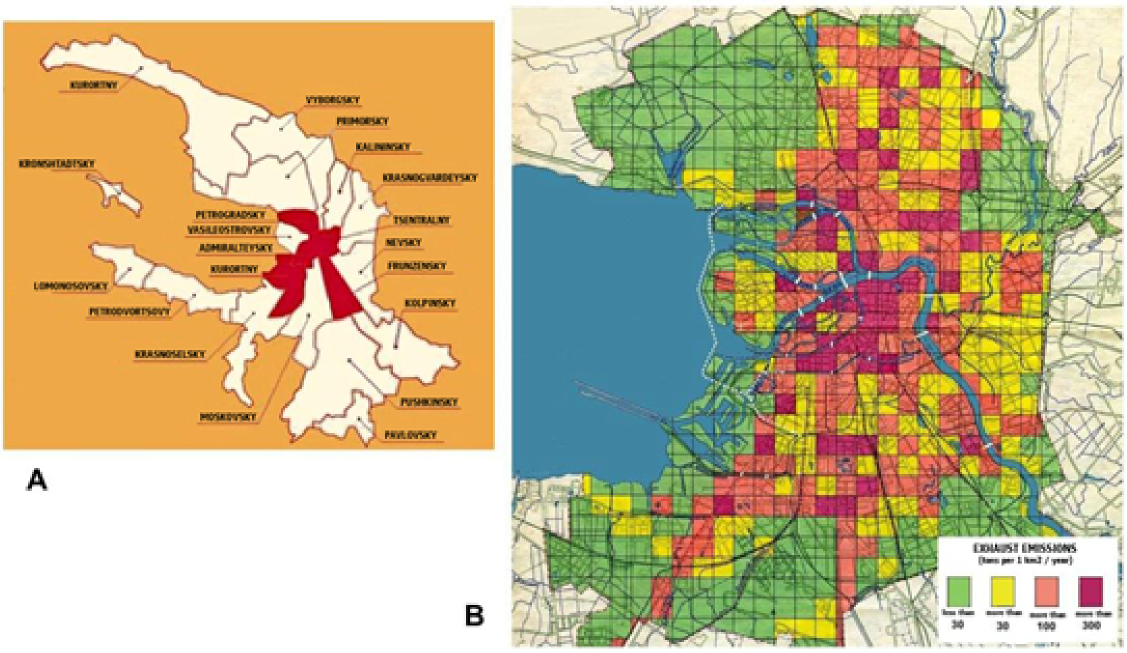

Figure 5. Environmental condition of Vasilyevsky Island in the 2000s: A — districts with the maximum noise levels (highlighted in red) in the city; B — distribution of exhaust emissions in Saint Petersburg, the planned WHSD is shown as a dashed line, the existing bridges — as white lines.

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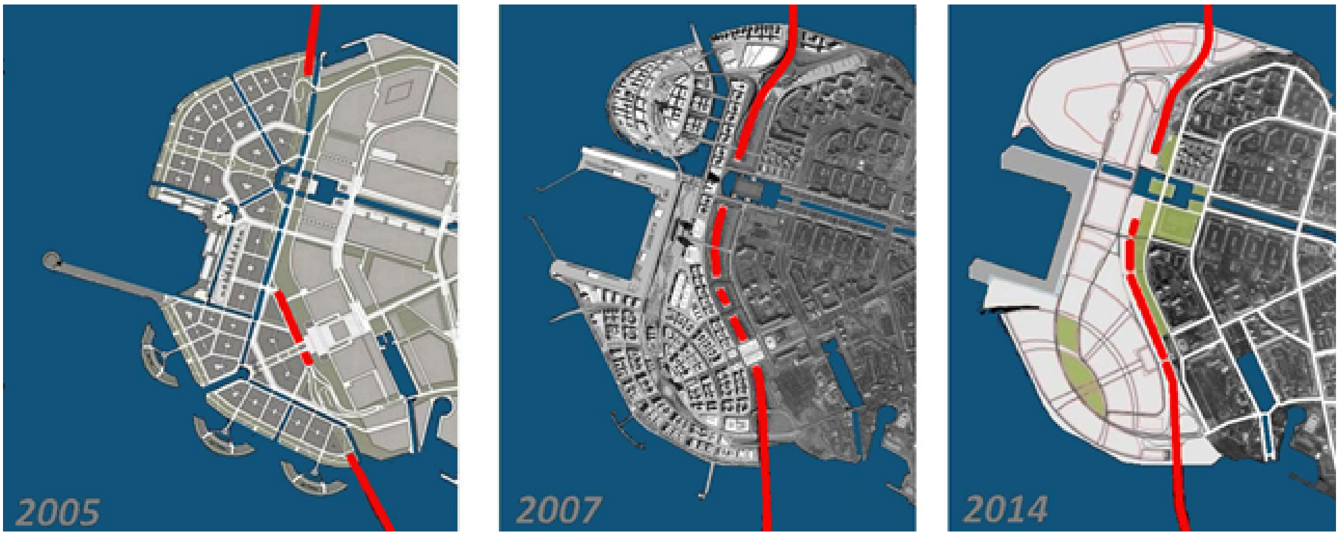

Figure 6. Concept of the development in the hydraulic fill area. On the left — one of the bid designs, on the right — approved versions as of 2007 and 2014.

units of the temporary Inrybprom exhibition soon became an international conference center. The building of the marine passenger terminal became a landmark. A multi-story hotel was planned to be built nearby (Figure 4c).

By the late 1990s, a subway station was built on the bank of the Smolenka River. Although improvement of the Morskaya Embankment was fragmental, the shoreline was used for promenades and picnics. A spontaneous beach appeared in the area. Apartments in elite complexes overlooking the water area of the Gulf of Finland were in demand. The residential area was enriched with facilities of city-wide and even international importance. Celebrities of national show business, looking for a place to build a signature amusement center, found the west of Vasilyevsky Island very attractive. It could compete with prestigious Moscow sites in Moscow City, on the Luzhnetskaya Embankment and Krasnye Kholmy. Photos of local landscapes were demonstrated as the evidence of Soviet (and later on — Russian) architecture achievements. A significant multi-functional complex was created and developed in the north-west of Vasilyevsky Island. It was noted in the 2000s that, in terms of demand for apartments and prices for residential property, Vasilyevsky Island was second only to the Tsentralny District and competed with the Petrogradsky District. Experts stated that Vasilyevsky Island could "take on the function of the center"(http://expert.ru/northwest/2015/09/transportnyij-triller-piterburhskago-manhettena/).

At the time, the Vasileostrovsky District was connected with other parts of the city only through the bridges located in its eastern part. They were always overloaded with cars, and they are raised at nighttime, cutting off the island from the rest of the city for several hours. Figure 2, where they are highlighted in yellow, demonstrates their role as transit routes between the southern and the northern parts of Saint Petersburg. The bridges are located at a distance from new coastal districts, and several dead-end district highways head to the west (Beacco, 2018). The specifics of this transport network impacted the environmental situation. In the early 2000s, Vasilyevsky Island was considered a relatively favorable district in the center of the city populated by 5 million people in terms of sanitary and hygienic indicators. The north-western part of the district also positively stood out in terms of traffic noise and exhaust emissions (Figure 5).

Western part of Vasilyevsky Island after the second hydraulic filling

The list of decisions that determined the development of Vasilyevsky Island at the beginning of the 21st century:

- 2000 — the governor of the city approved the Western High-Speed Diameter (WHSD) route. It was assumed that the road along the shore of Vasilyevsky Island would be hidden in a tunnel at a distance of 100 m from the water's edge or would stretch along the existing embankment (partially in an underground tunnel);
- 2004 — the Government of Russia approved the design of the marine passenger terminal at the western end of Vasilyevsky Island (https://regnum.ru/news/529857.html);
- 2005 — the Government of Saint Petersburg decided to perform another hydraulic filling in order to "develop the territories, build the Marine Facade and increase attractiveness of the city for tourists" (https://www.fontanka.ru/2005/06/21/144530/). The master plan provided for further development of the city urban-planning framework "with the formation of new public and business areas on the shore of the Gulf of Finland, on Vasilyevsky Island in the mouth of the Smolenka River, and in the area of the Shkiperskiy Canal".

The situation is unfolding: the hydraulic fill area and development in the west of Vasilyevsky Island are becoming the center of the architectural activities. Various options of the design concept are being formed and modified. The nature of the evolution is described in Figure 6:

- the water area in the hydraulic fill territory was reduced to the minimum, the canals disappeared. It is probable that the Smolenka River will be filled up like the Admiralteysky and Ligovsky canals (https://www.dp.ru/a/2018/10/24/

Otmitie_gektari). In 2014, it was decided that the road network should be reduced by half. All of this allowed increasing the areas intended for buildings.

- functional zoning in the hydraulic fill area was radically changed, since residential space was in high demand on the real estate market. In 2014, a new layout was approved. In this project, "all attention was drawn to residential areas, while the number of public and business facilities was reduced". Modification of the street network also contributed to the enlargement of the residential area (five blocks were joined with the neighboring ones, while only one block was divided). The number of residential buildings exceeded the number of non-residential buildings. In 2017, the project was modified once again. It resulted in urban densification in the southern part of the hydraulic fill area. Infrastructure and public order enforcement facilities were built instead of the green areas proposed before (https://www.dp.ru/a/2018/10/24/Otmitie_gektari).

- isolation of the WHSD route in a tunnel was considered needless, therefore, only the traffic way was deepened into a "half-tunnel". It was also proposed to arrange green spaces in the buffer sanitary protection zone and make a "linear park" there.

The WHSD route came to be considered as a part of the project for a bypass of the Saint Petersburg center, and it was decided to connect it in the southern part of the city with the passways along the Obvodny Canal and the renewed Makarov Embankment along the northern bank of Vasilyevsky Island (http://expert.ru/northwest/2012/33/poehat-byistree/, http://spbauto.org/news/transportnyy-obhod-centra-peterburga-kakim-on-budet). Figure 3 shows a new highway on the Makarov Embankment in a blue line. The same color is used for the WHSD exit on the southern bank of the island, near the Galernaya Harbor and Shkiperskiy Canal (https://www.fontanka.ru/2018/03/07/111/).

"The moment of truth" came on December 5, 2016. After commissioning of the WHSD central section, it turned out that the highway did not only provide a bypass of the city center, but also directed the traffic to the historical core using the shortest route, through the street-and-road network of Vasilyevsky Island. On December 5, a critical situation arose in the territory adjacent to the WHSD from the west: cars exiting the highway did not only jammed the local streets, but also moved through residential blocks. That came as a surprise. The authorities had to urgently start works to make an extra exit — that same exit that was found to be excessive during the project review in 2007 and was removed from the project to reduce the costs.

The strategic change of the transport situation and traffic redistribution on Vasilyevsky Island strongly affected the nature of its residential environment and conditions of commercial activities. The Administration of Saint Petersburg finds it important for the "construction to mean (both for the citizens of already developed areas and new tenants) comfort and harmonious development" (Albin, 2016). Such attitude towards the reconstruction of the city matches the "mutual benefit" program implemented in the Netherlands where renewal of the existing environment is used as a tool to improve the quality of life in adjacent territories (https://www.e-reading.club/chapter.php/104260/9/Glazychev_-_Urbanistika._chast%27_2.html). Unfortunately, these considerations did not affect the development in the Marine Facade area.

Environment and sociological issues in the west of Vasilyevsky Island. After the commissioning of the WHSD, the traffic increased significantly, and now, experts classify the entire district as one of the city center territories characterized by the maximum noise levels (https://nch-spb.com/). The optimistic layouts given in Figure 4 are now gone. Before the commissioning of the central part of the WHSD, the following districts of Saint Petersburg had the maximum noise level: Tsentralny; Admiralteysky; Frunzensky; Kirovsky; Petrogradsky. At the time, it was emphasized that the Morskaya Embankment in the Vasileostrovsky District could become one the disadvantaged (in terms of noise pollution) districts because of the Western High-Speed Diameter that was built in this part of the city (https://spbguru.ru/advice/105-samye-shumnye-rajony-sankt-peterburga). The predictions proved right, and now, the Tsentralny, Admiralteysky, Vasileostrovsky and Frunzensky Districts are included in a list of districts characterized by the maximum noise levels in the city (https://www.spb.kp.ru/daily/26756.7/3785916/).

The situation changed most noticeably in the residential blocks adjacent to the highway. The wide WHSD divided the residents of Vasilyevsky Island into two conflicting groups: those living in the "mainland" part of the island and new tenants in the hydraulic fill area. However, the controversies recede into the background when it comes to the assessment of the influence the highway has on the quality of apartments. Real estate experts state that "the hydraulic fill area troubles residents of the neighboring houses; residents of the buildings on Vasilyevsky Island facing the Morskaya Embankment will hardly be delighted with the new project" (https://www.novostroy-spb.ru/statyi/namjyvnjye_territorii_chto). The opinion of the sociologist is confirmed by those living in new buildings in the hydraulic fill area: according to them, they cannot withstand the noise from transport. They say that "one of the peculiarities of living in the area is the hatred of all the other residents of Vasilyevsky Island. They use offensive words for us and our houses. It is understandable: they have been deprived of the embankment and the view of the gulf" (https://www.the-village.ru/village/city/places/284792-vo-alluvion). Appearance of new residential blocks turned into serious financial problems for dwellers of the blocks adjacent to the highway from the east: the panoramic view of the water area disappeared, and the cost of hundreds of apartments dropped by 10–20% (http://www.metrium.ru/news/detail/skolko-stoit-elitnyy-vid-iz-okna/). The worsened environmental situation threatens even more losses[3]. Total losses of the owners of elite apartments in

[3] For instance, it is known that because of noise and contamination with exhaust gases, "apartments facing the Obvodny Canal are 30% cheaper than similar apartments at a distance from the embankment"

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the Marine Facade or Marine Cascade residential blocks can cost a fortune. Experts of Knight Frank St. Petersburg analytics company point out that "the highway just outside comfort-class buildings has already backfired on the cost of their apartments, and what is more important, on the liquidity" (Baranova, Kegeyan, 2018). It is unknown if this was taken into account in the economics of the project or what to expect in future.

However, significant changes in the transport infrastructure of the island gave a start to active urban-planning development of the district and triggered major investment projects in its western part. It became possible to gainfully use the view of the Gulf of Finland and closeness to the city center, which increased the demand for the real estate (http://www.proestate.pro/news-new/item/234-news-1-6). According to the experts' predictions, a "real construction boom" started in the Vasileostrovsky District (https://ktostroit.ru/news/269775/). The rate and nature of the territories' transformation in the western part of the island can be compared to the active reconstruction of the Strelka (Spit) in its eastern part in the 1990s[4].

Urban densification started on the eastern side of the WHSD. It appeared that the city needed public and business facilities that had been abandoned during the revision of the concept for development of hydraulic fill areas in 2014: a huge business center is under construction on the Shkiperskiy Canal (http://kanoner.com/2017/10/02/157077/, https://nsp.ru/news/8887-morskaya-rezidenciya-gazproma), and it is planned to build an elite hotel for 300 rooms (approximately in the area where it was planned in the 1980s – see Figure 4C) (https://www.dp.ru/a/2018/06/20/JElitnaja_zhizn_Lenjekspo). A culture and leisure center is rapidly developing in the vicinity: so far it occupies 4 ha of the coastal area of the former factory, but it is planned to use 15 ha (https://daily.afisha.ru/cities/8796-port-sevkabel-kakim-budet-novoe-mesto-na-kulturnoy-karte-peterburga/). The Song Theater, a project of a Moscow celebrity, us struggling for a construction permit (https://www.fontanka.ru/2019/02/22/049/). Housing demand in the habitable urban environment is stable, and new elite residential blocks are being built at all available sites (https://www.kommersant.ru/doc/3628672).

Prospects of the hydraulic fill area

Additional urbanization pressure on the west of Vasilyevsky Island is conditioned by the fact that it became a part of a chain of those super-projects that have appeared recently, are considered symbols of Saint Petersburg and determine the new image of the eastern coast of the Neva Bay: a 462 meter high tower of the Lakhta Center, a flying saucer of the Gazprom Arena stadium, cable-braced bridges of the WHSD with 125 meter tilted towers (https://mir24.tv/articles/16306594/novye-simvoly-sankt-peterburga). Development of this territory makes it possible to locate here additional city-wide facilities, which matches the strategy of the Saint Petersburg master plan, means broadened borders of the city center and corresponds to the objective of the Marine Facade project set in 2005 (https://whsd.ru/tzeli-i-zadachi-projecta.html). Since local territorial reserves are not limitless, investors will soon turn to the water areas of the Marine Facade beyond the hydraulic fill territories and the water area of Markizova Luzha. It is reported that even environmentalists think that it is necessary to control the development of the Neva hydrostructure (https://news.rambler.ru/other/41314381/?utm_content=rnews&utm_medium=read_more&utm_source=copylink). There are many grounds for city expansion through new hydraulic fill areas:

- economic: just like in the beginning of the 20th century, hydraulic filling is cheaper than purchasing land in the city. It is known that projects that were initially implemented in hydraulic fill areas were approximately 30% cheaper than similar facilities in the island part of the district (https://www.dp.ru/a/2018/05/30/Namiv_ne_huzhe_gollandskogo). The cost of land plots in Saint Petersburg currently reaches RUB 600 mln per 1 ha, while 1 ha in a hydraulic fill area costs approximately RUB 100 mln. It is assumed that expenses for hydraulic filling can be less (about RUB 74 mln per 1 ha without expenses for utilities) at the depth of 5 m (https://www.kommersant.ru/doc/3628672).
- commercial: Apartments with a water view are in demand in Saint Petersburg, despite being more expensive. "Location on a shoreline increases the cost of apartments. Actually, the cost of an apartment with a water view is on average 30–40% higher than the cost of neighboring premises of a similar area, but without such view. In individual premium projects, the extra cost for a water view reaches 45%". The prices for apartments with a panoramic view are 15–20% higher (https://www.portspb.ru/Arhiv/news30/postid/own_news/5826?tempage=vis_index,vis_index). This reminds us of 2007, when German Gref, who was the Minister of Economic Development and Trade, pointed out that a "water view" was the main factor that had an impact on housing prices in Saint Petersburg (http://www.rosbalt.ru/piter/2014/04/12/1256036.html).
- technological: new technologies currently used reduce the period of compacting the soil hydraulically filled in the shallows (https://www.mfspb.ru/proekt-morskoj-fasad/tekhnologiya.html). At the present time, soil compaction takes 9 months, and then underground utility systems can be laid and construction can be started (https://www.svoboda.org/a/132544.html).
- legal: development of empty plots in the existing built-up area is often associated with complex ownership rights and legal assignment of the new status, and a new hydraulic fill area resolves those problems fast and easy.

Unfortunately, in development of the hydraulic fill areas, another important factor is ignored: coastal districts are highly valuable territories attracting city

[4] This territory became a magnet for solid investments when the Birzhevoy Bridge and the new highway were built. Two administrative buildings were erected here in a short time, as well as a large clinic complex. A shocking proposal to construct a huge concert and exhibition center near the Stock Exchange and Rostral Columns was made. New facilities made such a radical change to the image of the architectural ensemble (a monument of the Russian Empire style) that they are called manifestations of "architectural vandalism of the late 19th century" (Lisovsky, 2004)

residents, that is why multi-functionality is typical for the area development. Experts emphasize that "coastal areas are in high demand and used not only for parks, but also for museums, tourist attractions, leisure areas, commercial and residential development" (Rybczynski, 2014). Currently, the Vasileostrovsky hydraulic fill area has no public or business functions. The new areas are filled only with multi-story residential buildings and micro-district public facilities, which does not correspond to the objectives of the Marine Facade project (Feng et al., 2018).

This results in fair criticism and shows that the city design and construction complex does not guarantee success in solving non-standard urban-planning tasks. For three quarters of a century, it was oriented to issues of large-scale residential construction, and large residential areas in peripheral districts of the city were its objects, since there was no room in the city center for such facilities (Fraser, 2019). An approach well-honed in Kudrovo or Parnas became instrumental in the development of the coastal part of the city center on Vasilyevsky Island. We can list main indicators of the fact that a set of conventional organizational and urban-planning solutions well-honed in the development of dormitory districts in the peripheral part of the city was used in unique coastal territories adjacent to the historical center:

- the city assigned the rights to the water area that was reserved for the development (476 ha of shallow waters) to an investment company, and that drastically restricted its opportunities to influence the implementation of the plans. In foreign countries, complex development projects are implemented under strict control and with participation of authorities (https://www.fontanka.ru/2013/11/26/175/). In Hamburg, the city allocated EUR 2.5 bln for the implementation of the HafenCity project, counting on private investments of EUR 8.5 bln. Nevertheless, the city authorities have a decisive influence on the situation by means of land allocation for new buildings (http://www.berlogos.ru/article/iskusstvo-gradostroitelstva-gamburg/). It should be noted that relative success of the "waterfront" was achieved in the 1970s–1980s through the use of proper organizational forms and assignment of the status of an "experimental project".

- the WHSD has a unique position in the structure of the territory in the hydraulic fill area. In terms of the most crucial parameters, it matches the model projects adopted in the international practice for suburban territories with loose low-rise development: speed of 110 km/h, 8 traffic lanes, noise protection through embedment with slight slopes on the edges;

- the architectural and urban-planning solutions that contradicted the focus on the maximum volume of residential areas were consistently dismissed from the project. The balance of the territories implies the reduction of the water areas, green spaces and the street-and-road network. In 2014, when the project was adjusted, "all attention was drawn to residential areas, while the number of public and business facilities was reduced" (http://kanoner.com/2014/12/31/142780/). All possible efforts were made to increase the number of floors in buildings and development density (for example, reportedly, it was permitted to the NTVO company to erect residential buildings in the hydraulic fill area instead of commercial buildings and increase the height of buildings in the area of 15 ha (https://m.fontanka.ru/2016/12/24/093/). The architect's scope of activities reduced, and there was less and less space left for artistic and aesthetic ambitions: "An architect could only make ornamentals without changing the form determined by the dominating conditions" (Ostrowski, 1979). Saint Petersburg architects lament: "Whatever you do, you will get another Kupchino" (http://novayagazeta.spb.ru/articles/10277/).

To conclude, we can use the words spoken during a meeting of the Saint Petersburg City-Planning Council: "The level of architecture in the hydraulic fill area is kind of a "mirror" of the society and the city... We have what we deserve" (http://luna-info.ru/discourse/sealess-spb/). in 2005, an option to transform the new coastal territory into the "second Venice" was considered, and in ten years, all the efforts were in fact limited to preparation of sites for rental housing construction (Tasan-Kok et al., 2019).

Conclusion

The Saint Petersburg Marine Facade project might get second wind. The city authorities are concerned with the fact that the contract for the hydraulic filling and development of the territories has been completed by 67% only, but it is close to the expiry date. It is assumed that the project implementation may be extended till 2026, and the Government of Saint Petersburg Government may stipulate for "changes in the purpose of the northern part of the hydraulic fill area" (https://ktostroit.ru/news/287543/).

Prospects of the WHSD on Vasilyevsky Island. N.I. Yaveyn predicts further active urbanization of the territory in the east of the Neva Bay. He thinks that in time, the "Western High-Speed Diameter (WHSD) will really become a diameter and will cross the center of the new city district" (https://piter.tv/event/Zasluzhennij_arhitektor_podderzhal_proekt_namivnih_ostrovov_v_Peterburge/). The reference to the WHSD attracts attention to its future since:

- the highway has a strategic importance not only for the Saint Petersburg urban-planning complex, but also for a significant territory in the north-west of the Russian Federation;

- the WHSD in the hydraulic fill areas of Vasilyevsky Island definitely determines the image, functions and functional utility characteristics of this part of the district. In spite of the initial concept, the WHSD is not only a bypass of the city center. Like the ring road, it has become a part of the street-and-road network of the city (http://expert.ru/northwest/2012/33/poehat-byistree/).

The WHSD solution implemented in the hydraulic fill area does not match the idea of a highway passing through the center of a highly urbanized district. We can state with a high degree of accuracy that the consequences of the choice made for Vasilyevsky Island will have their impact for a long time, and the related issues will aggravate when the houses in the hydraulic fill area are inhabited and the

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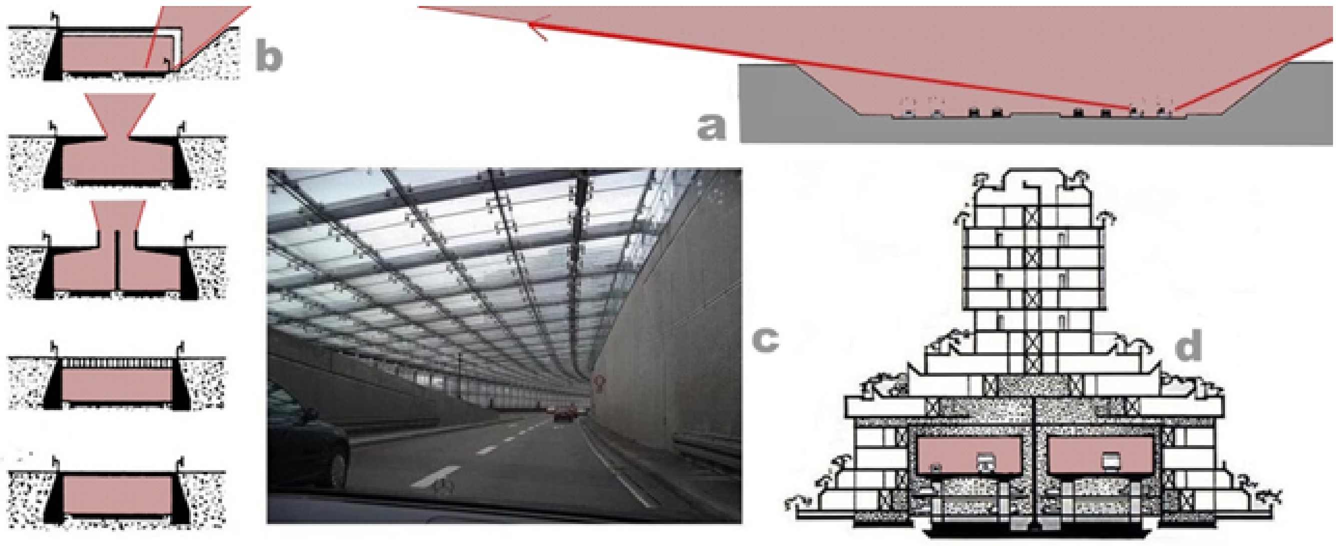

Figure 7. Noise protection of highways in urbanized zones (sound pollution areas are highlighted): a — cross-section of the WHSD on Vasilyevsky Island, b — options of noise insulation in Germany, c — a tunnel of the ring road in Munich, d — an option for enclosure in the Schlangenbader Straße residential area, Berlin.

predicted traffic increase proves true (https://www.fiesta.city/spb/news/tsifra-dnya-200-000-mashin-proezzhaet-po-tsentralnomu-uchastku-zsd/). Such laying of a multi-lane highway through a residential area in the city center has no analogues in the world. There is a good chance that the central section of the WHSD has become a unique landmark that will be remembered by city guests as a symbol of modern Saint Petersburg. Cities that have accumulated significant experience in laying highways prefer to avoid such solutions and minimize contacts between highways and residential areas, since it is associated with technical difficulties, additional expenses, lawsuits and social tension (https://de.wikipedia.org/wiki/Bundesautobahn_100).

The city folk in the west of Vasilyevsky Island think that they find themselves "on the sidelines of the highway" (https://www.ntv.ru/novosti/1729209/). But we should make it clear: it is a suburban highway. As early as during the construction of the highway, experts pointed out that the Morskaya Embankment in the Vasileostrovsky District could become one of the disadvantaged districts due to the noise from transport (https://spbguru.ru/advice/105-samye-shumnye-rajony-sankt-peterburga). The developers took into account the data of the Saint Petersburg ring road, where the "noise pollution" spreads to 320–1,100 meters from the traffic way (https://saint-petersburg.ru/m/society/bespalov/360590/), and arranged for noise protection. However, they used a solution that is efficient only in low-density territories with low-rise buildings, where the price for land and construction costs are relatively low. Although, noise protection walls provided by the design were never installed on Vasilyevsky Island (https://ok-inform.ru/stroitelstvo/regional/91263-kak-proveryayut-zsd-bez-shuma-i-pyli.html): there was a reason for their rejection as they could become a two-row fence across the island.

Experts point out that Russia has one of the strictest standards for noise protection in the world, but no due attention is given to compliance with those standards (https://nch-spb.com/). As for Saint Petersburg, the "syndrome of a historical city" also shows: in the assessment of the WHSD design review results, attention is drawn to those facilities that have historical and cultural significance and will be "affected" by the construction works. It is also noted that installation of noise protection screens will be required in some places.

Currently, the area with environmental problems covers the whole hydraulic fill territory as well as the residential blocks adjacent to the WHSD from the east. Noise and exhaust emissions make it impossible to ensure luxury in the expensive quarters that are currently built for wealthy clients from the neighboring Lakhta Center and High Court (http://www.rbcplus.ru/news/5ad86d597a8aa91bd267846e?ruid=NaN).

The administration of the highway argues that "the central section of the WHSD has been built in full compliance with the design documentation that passed all required reviews and was approved by the General Board of State Expert Review", and promises to install noise protection screens. Probably, during the review, the specific nature of the hydraulic fill area was not taken into account: high-rise residential buildings dominate there. According to the residents of a new house in the hydraulic fill area, "it is really noisy... starting from the fifth floor (but there is no noise in the apartments below). The noise level is clearly too high, but we have not conducted a review yet. However, we are going to do that" (https://www.the-village.ru/village/city/places/284792-vo-alluvion). The reason for that is explained in a diagram in Figure 7a: the technical solution used in the hydraulic fill area reduces the noise by the highway near the ground, but it screens off the sound and directs it to the higher floors of high-rise buildings. We can only hope that the review planned by the residents and specified in the construction standards will be conducted. It states that "in case of high-rise buildings, measurement points should be also chosen at the level of the highest floor of a building" (State Standard GOST 23337-2014). In any case, the city will have to make a choice: either the WHSD on Vasilyevsky Island stays as it is or its parameters are brought into compliance with the European indicators.

For European cities with the population of more than 100,000 people, compulsory monitoring of the motor transport impact on the urban environment is prescribed, and measures for protection against transport noise become stricter with the transition of highways from peripheral territories to the center:

- the allowable speed decreases;
- protective screening of the traffic way with side shields and roofs is strengthened.

At a section where the autobahn crosses the existing residential area, the highways are hidden in tunnels or even laid at the basement level of city buildings (Figure 7). Open public spaces frequently appear above underground highways. The speed on a coastal overpass in Genoa is 60 km/h. In Berlin, the speed on federal highways crossing the city is 60–80 km/h, and the speed on some of them at nighttime is only 50 km/h. In the center of Berlin, the TTS tunnel with the length of 2.4 km, designed for 50,000 cars per day was built in 2006. There are 13 transport tunnels in the Middle Ring in Munich. In Hamburg, three tunnels with the total length of 3,753 m are being constructed at a renewed section of the A-7 Autobahn.

Proposals to use ideas that were unusual and seemed eccentric 15–20 years ago are made, and they are considered as possible prototypes of modern facilities. In 1962, a bus terminal and a residential complex of four 32-storey buildings were built in New York above the 12-lane highway near the George Washington Bridge. In 1980, a 14-storey residential building with the length of 600 m with almost 1,800 apartments was built in Berlin above the A-100 Autobahn (Figure 7d). At the time, it was perceived negatively, but in 2017, it became protected as a historical site, and in 2018, it was proposed to use it as a standard for another similar structure above the same autobahn (https://www.morgenpost.de/berlin/article214748501/Neue-Wohnhaeuser-ueber-der-Autobahn-A-100.html).

The history of the development in the hydraulic fill areas on Vasilyevsky Island shows that the rate of buildings' reconstruction in these territories continuously declines:

- the "service life" of a classic ensemble on the Strelka (Spit) was 70 years;
- the "access to the sea" planned in 1966 survived for about 50 years.

It is evident that in the new century, the rate of urban development grows, and the facilities built in the hydraulic fill area will soon have to change their image drastically. The Marine Facade project is still under development. The territory is built-up only partially, but "changes in the purpose of the northern part of the hydraulic fill area are already considered" (https://www.restate.ru/material/smolnyy-nameren-prodlit-dogovor-na-namyv-territoriy-v-o-168436.html).

Vasilyevsky Island has expressive evidences of dramatic and drastic transformations of famous architectural complexes both on the Strelka (Spit) in the east, and on the western coast. Currently, some features of the new stage of waterfront transformations, that cause concern, manifest.

However, the process is underway, and some adjustments may be made. We hope that this chance will be used wisely, and the new waterfront will not become a reflection of the state of the real estate market in the beginning of the 21st century, but will acquire impressive architectural objects that will symbolize the multifaceted image of the "Northern Capital of Russia".

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«МОРСКОЙ ФАСАД», ЗСД-АВТОБАН И ВАСИЛЬЕВСКИЙ ОСТРОВ КАК ЧАСТЬ ИСТОРИЧЕСКОГО ЦЕНТРА САНКТ-ПЕТЕРБУРГА

Леонид Павлович Лавров[1], Елена Геннадьевна Молоткова[2]

[1,2] Санкт-Петербургский государственный архитектурно-строительный университет
2-ая Красноармейская ул., 4, г. Санкт-Петербург, Россия

[1] Автор, ответственный за переписку: leonid.lavrov@gmail.com

Аннотация

Введение: На примере реализуемого проекта «Морской фасад» выявляется разрыв между стратегическими установками развития Санкт-Петербурга, определенными системой городского планирования и закрепленными в генеральном плане города, и реальным преобразованием архитектурной среды Васильевского острова. **Цель исследования:** Выявить наиболее значительные упущения, допущенные в ходе реализации и многократных корректировок первоначальной концепции. **Методы:** Сопоставительный анализ ключевых положений исходной концепции и показателей формируемой в настоящее время городской среды. **Результаты:** Выявлена недооценка радикального изменения градостроительной ситуации в центре города, вызванной прокладкой скоростной автомобильной магистрали по западной части Васильевского острова. Показано, что инерционность сложившейся в Санкт-Петербурге проектно-строительная системы, которая на протяжениии многих десятилетий была ориентирована на массовую жилую застройку обширных периферийных территорий, не позволяет ей решать возникающие при этом проблемы развития высокоурбанизированной среды. Излагаются факты, показывающие, как последовательная корректировка исходной концепции создала базу для формирования в уникальной береговой зоне центра спальных жилых кварталов периферийного типа и прокладки автобана пригородного образца. Определен перечень мер, которые могли бы уменьшить связанное с этим негативное воздействие на селитебные территории. Отмечается, что негативный опыт реализации проекта «Морской фасад» в Санкт-Петербурге должен быть учтен в градостроительной практике других метрополий России.

Ключевые слова

Архитектура Санкт-Петербурга, городское планирование, акватории и береговые территории, центр и транспортный каркас.

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Surface Transportation Engineering Technology

ACTUALIZATION OF THE QUANTOMOBILE FORCE BALANCE IN THE PITCH PLANE

Jurij Kotikov

Saint Petersburg State University of Architecture and Civil Engineering
Vtoraja Krasnoarmejskaja st., 4, St. Petersburg, Russia

Email: cotikov@mail.ru

Abstract

Introduction: As we approach introduction of quantum engines (QE) into the transportation industry, it will be useful to analyze properties of a hypothetical automobile with a QE (quantomobile). The purpose of the study is to conduct a calculation analysis of the quantomobile force balance and options of its motion in the pitch plane. **Methods**: Assuming that it is possible for a quantum engine to generate the vertical component of the thrust vector (of anti-gravity orientation), a two-dimensional approach to analyze the quantomobile force balance is used. A generalized force balance equation for all quantomobile motion modes in the longitudinal pitch plane is derived. Five typical motion modes are identified. The graphic images provided represent a part of the combination of analytical actions intended to record and comprehend the distinctive end points and curves. **Results**: The numerical examples based on the mentioned force balance equation allowed us to construe the quantomobile motion modes in the pitch plane, as well as obtain a picture of uniform course motion of the quantomobile. **Discussion**. The analysis revealed that it was possible to minimize the thrust for maintaining constant speed under the middle degree of vehicle suspension. The derived force balance equation that matches the 2D option of quantomobile motion in the pitch plane can be expanded to the 3D option of vehicle motion. This will make it possible to assess the dynamics and energetics of quantomobile motion in a three-dimensional space in more detail, as well as compare such vehicles with other vehicles operating in this space, e.g. planes, helicopters, etc.

Keywords

Automobile, quantum engine, quantum thrust, quantomobile, pitch plane, force balance.

Introduction

Fundamental discoveries of the quantized space-time (QSP) with its structural particle — the quanton — in combination with the theory of Superunification can radically change the principles of power generation and conversion (Leonov, 2002, 2010, 2018). One of the conclusions of the theory of Superunification is the possibility of direct extraction of energy from the physical vacuum.

A new generation of vehicles with quantum engines (QE) — quantomobiles — will replace automobiles. The main difference of the QE from the ICE is that the QE directly generates thrust, which can be applied to the vehicle body to create motion (Brandenburg, 2017; Fetta, 2014; Frolov, 2017; Shawyer, 2006; Tajmar et al., 2007).

Changing the thrust vector position from horizontal to inclined (almost to the vertical plane) will allow creating a vertical component of traction that can be used to overcome gravitation and get the quantomobile above the bearing surface to establish the quantum flying car mode (Kotikov, 2018a).

In earlier papers (Kotikov, 2018a, 2018b, 2018c, 2019a, 2019b), the author described individual aspects of the topic. In future, quantum energetics will be mastered and used in mass consumption. In this regard, now it would be useful to study theoretical aspects and specifics of future quantomobiles.

In the papers mentioned above, the author described basic differences between quantomobiles and modern automobiles in terms of design and loading pattern, as well as functional differences in forming and managing traction and speed properties of automobiles and quantomobiles — with regard to motion along the bearing surface (without suspension of a vehicle above the surface). Examples of calculating traction and power consumption are given, and a relevant quantitative analysis has been conducted.

Purpose and tasks of the study

Purpose of the study: deepen the knowledge of the force balance and options of its use in the longitudinal pitch plane, including with breakoff from the bearing surface and suspension above it.

For achievement of this purpose we plan the decision of following tasks:

1. Develop a generalized force balance equation for all quantomobile motion modes, including breakoff from the bearing surface.
2. Provide graphic images as a part of the combination of analytical actions intended to record and comprehend the distinctive end points and curves.
3. Provide numerical and graphic examples.
4. Discuss the results and define the prospect of topic elaboration.

Methods

Thrust generation by a quantum engine and decomposition of the thrust vector

The basic principle of QE operation is that the vacuum environment is deformed in the body of the QE operating unit that actively interacts with the vacuum environment of the QE. The internal thrust appears in the body of the operating unit (thrust $\boldsymbol{F_T}$). This thrust rests upon an elastic fragment of the continuous vacuum environment (field) and, when applied to the QE structure, it can make it move relative to the field (Brandenburg, 2017; Fetta, 2014; Frolov, 2017; Leonov, 2002, 2010, 2018; Shawyer, 2006; Tajmar, 2007).

Let us decompose the three-dimensional thrust vector into unit vectors (Leonov, 2018):

$$\mathbf{F_T} = \mathbf{F_{Tx}} + \mathbf{F_{Ty}} + \mathbf{F_{Tz}} \quad (1)$$

The scalar form of this equation is as follows:

$$F_T = \sqrt{F_{Tx}^2 + F_{Ty}^2 + F_{Tz}^2} \quad (2)$$

Equations (1) and (2) are general initial equations for calculation of quantomobile motion both along the bearing surface and at vehicle breakoff from the surface (in the quantum flying car option), as well as in the mode of lateral motion correction.

Within the tasks of the study, i.e. only longitudinal pitch motion of the vehicle, α, equations (1) and (2) take the following form:

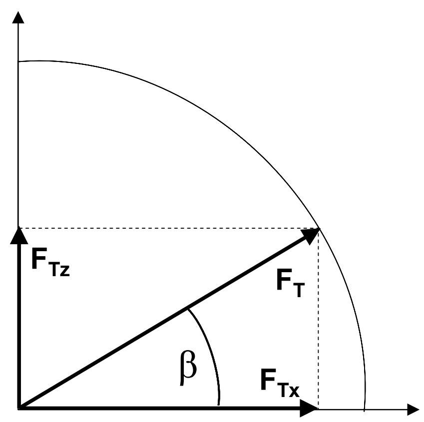

Figure 1. $\boldsymbol{F_T}$ thrust decomposition into the horizontal ($\boldsymbol{F_{Tx}}$) and vertical ($\boldsymbol{F_{Tz}}$) components: β — thrust angle $\boldsymbol{F_{Tz}}$ relative to the horizon.

$$\mathbf{F_T} = \mathbf{F_{Tx}} + \mathbf{F_{Tz}} \quad (3)$$

The scalar form of this equation is as follows:

$$F_T = \sqrt{F_{Tx}^2 + F_{Tz}^2} \quad (4)$$

Graphically, it is given in Figure 1.

It can be seen that representing the F_T thrust value by the arithmetic sum of scalar values of the F_{Tx} horizontal thrust and F_{Tz} vertical carrying capacity (i.e. $F_T = F_{Tx} + F_{Tz}$) will be deeply incorrect (since there is geometric addition of the vectors). The quantomobile force balance analysis will therefore differ from that of the common automobile force balance, which will be described below.

Developing a generalized quantomobile force balance equation

Let us start deriving a generalized quantomobile force balance equation from the known equation of automobile motion along the horizontal bearing surface (Jacobson, 2016; Jante, 1958; Kotikov, 2006; Selifonov, 2007) (it corresponds to motion of a quantomobile with only driven wheels, without any vertical suspension of the vehicle):

$$F_{Tx} = P_T = P_f + P_w + P_j = G_q f_{wh.0}(1 + f_{wh.v} V_x^2) + \\ + k_{w.x} S_{front} V_w^2 + \frac{G_q}{g} a_x \cdot (1 + \delta_{wh}), \quad (5)$$

where P_T is the thrust, N;

P_f is the force of resistance to the rolling of driven wheels, N;

P_w is the wind resistance, N;

P_j is the vehicle inertia force, N;

G_q is the quantomobile weight, N;

$f_{wh.0}$ is the coefficient of resistance to the rolling of driven wheels at a speed close to zero, and F_{Tz} = 0 (if there is no suspension or pressing-down of the vehicle);

$f_{wh.v}$ is the velocity coefficient of resistance to the rolling of driven wheels 3–4 s^2/m^2 (Jacobson, 2016; Jante, 1958; Selifonov, 2007);

V_x is the current speed of longitudinal (course) motion of the vehicle, m/s;

$k_{w.x}$ is the horizontal (longitudinal) wind shape coefficient, $N \cdot s^2/m^4$;

S_{front} is the frontage area of the vehicle, m^2;

V_w is the longitudinal velocity of the vehicle relative to the wind (in the present study, $V_w = V_x$), m/s;

g is the gravitational acceleration, m/s^2;

a_x is the longitudinal acceleration of the vehicle, m/s^2;

δ_{wh} is the rotational inertia coefficient of driven carrying wheels.

At actualization of the vertical component of the thrust F_{Tz}, modernization of equation (4), taking into account (5), generally results in the following expression:

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$$F_T^2 = F_{Tx}^2 + F_{Tz}^2 = (f_{wh.0}(1 + f_{wh.v} \cdot V_x^2) \cdot (G_q - F_{Tz}) \Big|_{F_{Tz} \le G_q} + k_{w.x} \cdot S_{front} \cdot V_w^2 + \frac{G_q}{g} a_x \cdot (1 + \delta_{wh}))^2 + \left(k_{w.z} \cdot S_{plan} \cdot V_z^2 + \frac{G_q}{g} a_z \Big|_{F_{Tz} > G_q} + F_{Tz}\ G_q \right)^2 \quad (6)$$

where $k_{w.z}$ – vertical wind shape coefficient, N·s²/m⁴;

S_{plan} is the vehicle area in plan view, m²;

V_z is the vertical motion speed of the vehicle, m/s;

a_z is the vertical acceleration of the vehicle, m/s²;

$\big|F_{Tz} \le G_q$ is the range of allowable values of F_{Tz} in the pressing-down mode (downwards – to improve stability) or partial suspension of the vehicle (without breakoff from the bearing surface);

$\big|F_{Tz} > G_q$ is the range of allowable values of F_{Tz} in the mode of full suspension of the vehicle above the bearing surface (with possible breakoff from the surface).

Equation (6) represents a generalized expression of the quantomobile force balance that comprises all typical cases of quantomobile motion:

1. only longitudinal motion – in the vehicle pressing-down mode, with the vertical component of the thrust $F_{Tz} < 0$, i.e. at downward motion;
2. only longitudinal motion – in the mode of a conventional automobile with no vertical component of the thrust, $F_{Tz} = 0$;
3. longitudinal motion – in the mode of partial suspension of the vehicle, without wheels' breakoff from the bearing surface, when $0 < F_{Tz} < G_q$;
4. longitudinal boundary motion – with the wheels touching the bearing surface (without connecting to it, but without vehicle breakoff upwards), when $F_{Tz} = G_q$;
5. longitudinal and vertical (with vehicle breakoff from the bearing surface) – when $F_{Tz} > G_q$.

There are some peculiarities of using equation (6):

- for cases 1-3, the coefficient of resistance to the rolling of driven wheels at a speed close to zero $f_{w.0}$, as well as the rotational inertia coefficient of wheels δ_{wh} are relevant (e.g. $f_{w.0} = 0.3$; $\delta_{wh} = 0.04$);
- for cases 5) and 6), these coefficients become zero (which is, however, backed up in equation (6) by determinative ranges of values of F_{Tz}: $\big|F_{Tz} \le G_q$ and $\big|F_{Tz} > G_q$;
- the term of equation "min(F_{Tz}, G_q)" represents a force to overcome gravity created by the vehicle mass: partially – when at $F_{Tz} \le G_q$, it is not physically possible for the vehicle to go upwards, or at $F_{Tz} > G_q$, when gravity is overcome completely, it is possible for the vehicle to break off due to the remaining force $R_{FTz} = F_{Tz} - G_q$;
- Equation (6) does not take into account vertical movement of the vehicle when the value F_{Tz} changes in cases of motion 1-3, which (though insignificant) will occur because of deformation of tires and soil flexibility. Vertically oriented speed and acceleration actualized in this case will be massively smaller than the speed V_z and acceleration az at vehicle breakoff with $F_{Tz} > G_q$ – therefore, we neglect those values in this study.

Results: special cases and their numerical examples

For the quantitative analysis, we choose a hypothetical quantomobile with the specifications of a similar automobile (KamAZ-4326) with a QE (instead of the ICE), used in the previous analysis (see in detail in (Kotikov, 2018c, 2019a)), under extremely severe conditions of motion (sand, silt, swamps (Pauwelussen, 2007; Popov, 2003)):

G_q = 88,000 N; Sfront = 7 m²; $f_{w.0}$ = 0.3; $f_{wh.v}$ = = 4·10⁻⁴ s²/m²; $k_{w.x}$ = 0.5 N·s²/m⁴.

We will also use the following values of variables determining the force balance of the quantomobile under consideration for vertical components of its motion:

$k_{w.z}$ = 0.8 N·s²/m⁴; S_{plan} = 7·2.5 = 17.5 m².

Let us agree that the maximum value of the QE thrust, with this value maintained in the pitch plane in the range of directions β = 0–90°, equals F_T = 90 kN (with a small margin relative to the quantomobile weight $R_T = F_T - G_q$ = 90–88 = 2 kN). The remaining thrust force R_T = 2 kN is provided for the quantum flying car to be able to move horizontally in a suspended condition or break off from the bearing surface.

Let us provide calculations of two values of F_{Tz} for the automobile mode (without any suspension of the quantomobile, i.e. for case 2 when F_{Tz} = 0) at the steady uniform motion (a_x = 0), performed according to equation (6):

0 km/h: F_{Tx} = 88,000 · 0.3 =26,400 N;

67.2 m/s (242 km/h): F_{Tx} = 88,000·0.3 (1 + 4·10⁻⁴ · · 67.2²) + 0.5·7·67.22 = 88,000·0.3 (1 + 1.8063) + 15,805 = 74,086 + 15,805 = 89,892 N.

The quantomobile force balance at steady motion for the whole range of speeds is given as yellow *CD* curve in Figure 2. If the maximum value of the thrust is limited to, for example, 90,000 N, then the point of intersection of the curve with the limiting red line F_T = 90 kN will determine the maximum speed of quantomobile motion (here, 242 km/h = 67.2 m/s) at strictly horizontal direction of the thrust vector (no suspension of the vehicle).

At speeds *V* < 67.2 m/s, the available thrust resource can be used for vehicle acceleration. For instance, for the quantomobile under consideration, equation (6) can be converted as follows:

$$89892 - F_{Tx} = \frac{G_q}{g} a_x \cdot (1 + \delta_{wh}), \quad (7)$$

where δ_{wh} = 0.04 is taken.

Then, the following working equation can be derived for horizontal acceleration:

a_x = (89,892 – F_{Tx}) 9.81 / (88,000·1.04) = = (89,892 – F_{Tx}) / 9,329.

Initial acceleration at *V* = 0 km/h will be (89,892 – – 26,400) / 9,329 = 63,492 / 9,329 = 6.8 m/s².

The whole acceleration curve *AB* is given in Figure 2 in green. The field of conditions when acceleration of a non-suspended quantomobile is possible is colored in light green.

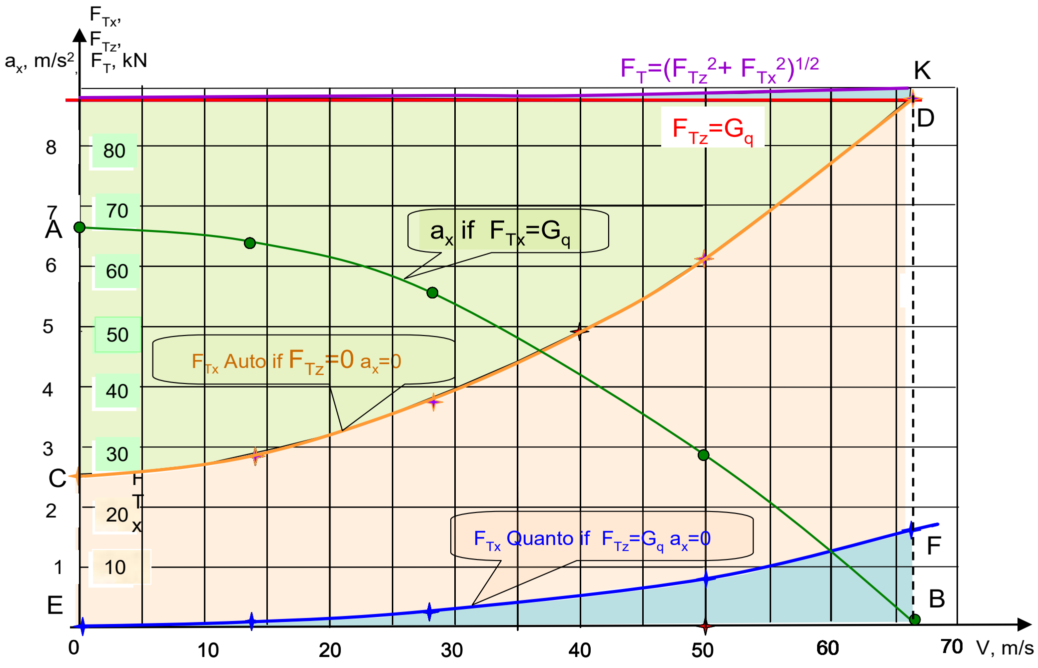

Figure 2. Force balance at steady motion of the quantomobile along the bearing surface with $f_{wh.0}$ = 0.3.

Let us review the use of equation (6) in the analysis of the moment of quantomobile breakoff (without fly-off) from the bearing surface (case 4 of the motion modes listed above, when $F_{Tz} = G_q$). In this case, $\delta_{wh} = 0$, $V_z = 0$, $a_z = 0$, and equation (6) can be simplified as follows:

$$F_T^2 = F_{Tx}^2 + F_{Tz}^2 = \left(k_{w.x}\cdot S_{front}\cdot V_w^2 + \frac{G_q}{g}a_x\right)^2 + (G_q)^2 \qquad (8)$$

Taking into account that $F_{Tz} = G_q$, the balance of horizontal forces can be simplified as follows:

$$F_{Tx} = k_{w.x}\cdot S_{front}\cdot V_w^2 + \frac{G_q}{g}a_x. \qquad (9)$$

At $a_x = 0$, the F_{Tx} value necessary to maintain uniform longitudinal (horizontal) motion (hovering, at the moment of wheels' breakoff from the bearing surface) (see the *EF* blue curve in Figure 2) is as follows:

at V = 0 km/h: F_{Tx} = 0.5·7·0² = 0 N;

at V = 67.2 m/s (242 km/h): F_{Tx} = 0.5·7·67.2² = 15,805 N (see point *F* in Figure 2).

Then, the required value of the QE thrust F_T will be:

$F_T = (F_{Tz}^2 + F_{Tx}^2)^{1/2}$ = (88,000² + 15,805²)^½ = = (7,744,000,000 + 249,798,025)^½ = (7,993,800,000)^½ = = 89,408 N (see point *K* in Figure 2).

The thrust angle can be found through the following equation:

$\beta = \arctan(F_{Tz} / F_{Tx})$ = arctan (88 / 15,805) = 79.82°.

Please note that there is practical coincidence of the thrust values for steady motion at the speed of 67.2 m/s in the automobile mode (case 2: $F_T = F_{Tx}$ = 89.9 kN) and in a fully suspended condition of the vehicle (case 4: $F_T = (F_{Tz}^2 + F_{Tx}^2)^{1/2}$ = (882 + 15.82)$^{1/2}$ = 89.4 kN). In other words, the course speed of 67.2 m/s can be achieved through actualization of the same thrust value ~ 90 kN, but by different methods: case 2 – horizontal thrust; case 4 – thrust angle β = 79.8° relative to the horizon. Such special combination will allow simplifying conceptual studying of numerous options when searching for the value and direction of the thrust for various degrees of vehicle suspension, but for the same speed (which will be shown below).

The orange field in Figure 2 (between the blue *EF* and yellow *CD* boundary curves) represents a set of all possible options of the force balance for various speeds at the change of the vertical component of the thrust F_{Tz} from 0 to G_q (please note that for the initial coefficient of wheel rolling resistance $f_{wh.0}$ = 0.3).

It should be noted that if the balance conditions in equation (9) are maintained, the following can be written for the longitudinal acceleration of a suspended vehicle (at $F_{Tz} = G_q$):

$$a_x = \frac{g}{G_q}\left(F_{Tx} - k_{w.x}\cdot S_{front}\cdot V_w^2\right) \qquad (10)$$

The maximum speed can be determined by setting $a_x = 0$:

$$V_{x.\max} = \sqrt{F_{Tx} / k_{w.x}\cdot S_{front}} \qquad (11)$$

The longitudinal acceleration at the initial moment of longitudinal motion of a suspended vehicle can be determined by setting $V_x = 0$:

$$a_x = \frac{F_{Tx}\cdot g}{G_q} \qquad (12)$$

The use of generalized equation (6) and its special cases (8–12) allows calculating the components of the thrust for options of quantomobile motion along the bearing surface at different degrees of suspension, up to the breakoff from the surface (see Table 1), as well as making a graphic presentation of the calculation results as a graph of spatial use of the thrust in the longitudinal pitch plane (Figure 3).

The objective was to identify the type of relationship between the thrust value, necessary for uniform motion at the set speed, and the degree of vehicle suspension.

Let us introduce some terms:

"degree of suspension" of the vehicle – ratio $\gamma = F_{Tz}/G_q$;

"maximum thrust" – thrust F_T of the maximum value and any direction in the pitch plane, ensured by the QE installation (here, F_T = 90 kN);

"sufficient thrust" – thrust $F_{T.st}$ of the value sufficient to maintain the set speed of horizontal **st**eady motion that, as a rule, does not coincide with the maximum thrust (in terms of direction) that ensures the same degree of vehicle suspension.

The following designations are taken for the new values in Table 1 and in Figure 3:

$F_{Tx.ac}$ – the horizontal component of the maximum thrust that ensures the set degree of vehicle suspension, maintaining the set speed (here, 67.2 m/s) and the possibility of further **ac**celeration;

$F_{Tx.st}$ – the horizontal component of the sufficient thrust necessary and sufficient to maintain the set steady speed of the vehicle of 67.2 m/s;

R_{FTx} – the difference between the values ($F_{Tx.ac} - F_{Tx.st}$) that ensures further horizontal acceleration a_x when the set speed of the vehicle of 67.2 m/s is achieved;

$F_{T.st}$ – the sufficient thrust to maintain the **st**eady set speed of 67.2 m/s;

R_{FT} – the difference between the values ($F_T - F_{T.st}$) that can ensure acceleration of the vehicle (a_x and/or a_z) when the set horizontal speed of the vehicle of 67.2 m/s is achieved;

β_{ac} – the maximum thrust angle F_T relative to the horizon;

β_{st} — the sufficient thrust angle $F_{T.st}$ relative to the horizon.

The algorithm of calculating the mentioned values is as follows:

1) $F_{Tz} = \gamma \cdot G_q$;
2) $\beta_{ac} = \arcsin (F_{Tz} / F_T)$;
3) $F_{Tx.ac} = \cos \beta_{ac} \cdot F_T$;
4) $F_{Tx.st} = P_f + P_w = f_{wh.0}(1 + f_{wh.v}V_x^2)(G_q - F_{Tz}) + k_{w.x}S_{front}V_w^2$;
5) $R_{FTx} = F_{Tx.ac} - F_{Tx.st}$;
6) $\beta_{st} = \arctan (F_{Tz} / F_{Tx.st})$;
7) $F_{T.st} = F_{Tz} / \sin \beta_{st}$;
8) $R_{FT} = \beta_{ac} \cdot F_T - F_{T.st}$.

Discussion

The target dependence of the horizontal component of the thrust vector, sufficient to maintain uniform motion of the quantomobile with a constant speed, on the degree of suspension turned out to be linear. This is understandable since the dependence determined by equation (13) is essentially linear, type $y = kx+c$, where y is $F_{Tx.st}$, $k = f_{wh.0}(1 + f_{wh.v}V_x^2)$, the argument x is the force of interaction between the vehicle wheels and the bearing surface ($G_q - F_{Tz}$), and the free term is $c = k_{w.x}S_{front}V_w^2$.

That peculiarity determines availability of the force reserve when the thrust is used in the medium zone of vehicle suspension, as shown in Figure 3, e.g. in point 4. The excess horizontal component of the thrust force R_{FTx} can be used to increase the course speed. Also, it is possible to increase the degree of vehicle suspension, which is beneficial in terms of reduced resistance to traction.

The linear nature of dependences (5), (6) and (13) (at constant speed) matches the simplest approach to vehicle motion modeling. It allowed solving the task of obtaining the picture of the thrust use in the pitch plane, as well as the task of developing the method of respective analysis. However, in reality, the functions are, of course, non-linear. This fact will undoubtedly affect the type of the target dependences (like the red line in Figure 3). The analysis will also become more complex when numerous speeds, roads and other attributes are used.

Table 1. Calculation of thrust components for options of quantomobile motion along the bearing surface with the coefficient $f_{wh.0}$ = 0.3.

Point No.	Degree of suspension γ	Thrust components, kN						Thrust angle relative to the horizon, *degrees*	
		F_{Tz}	$F_{Tx.ac}$	$F_{Tx.st}$	R_{FTx}	$F_{T.st}$	R_{FT}	β_{ac}	β_{st}
1	0	0	90	89.89	0.11	89.89	0.11	0	0
2	1/8	11	89.32	80.63	8.69	81.36	8.64	7.03	7.77
3	1/4	22	87.27	71.37	15.90	74.68	15.32	14.15	17.13
4	1/2	44	78.52	52.85	25.67	68.77	21.23	29.26	39.78
5	3/4	66	61.18	34.33	26.85	74.37	15.67	47.17	62.56
6	7/8	77	46.60	25.07	21.53	80.97	9.03	58.82	71.99
7	15/16	82.5	37.09	20.43	16.66	85	5	65.66	76.09
8	1	88	18.87	15.80	3.07	89.41	0.59	77.90	79.82
9	1.022	90	–	–	–	90	2	90	90

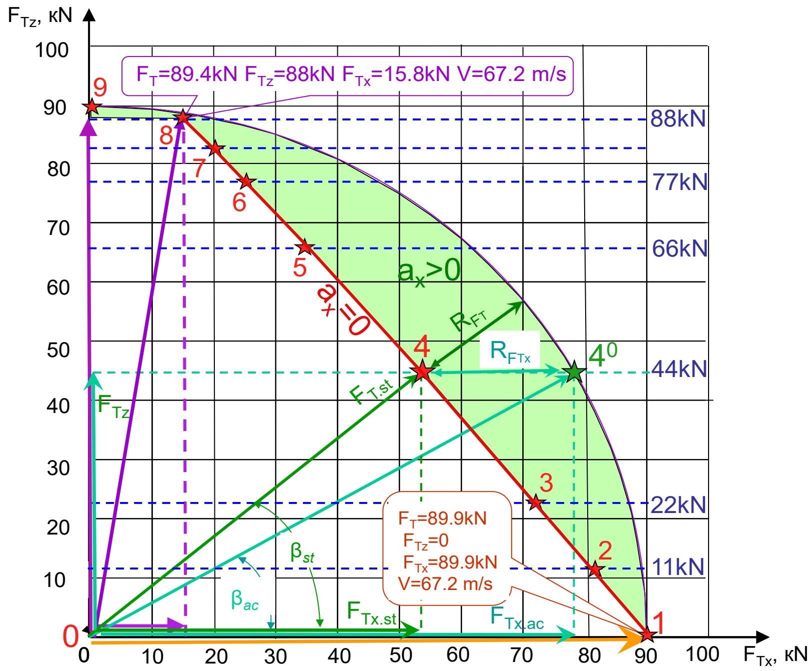

Figure 3. Graph of spatial use of the thrust in the longitudinal pitch plane.

The derived force balance equation that matches the 2D option of quantomobile motion in the pitch plane can be extended to the 3D option of vehicle motion (this independent task was not included in the list of the objectives).

Naturally, the 3D model should include lateral forces actualized in the transversal direction, as well as the moments of rotational motion forces of the vehicle, relative to all three axes of the coordinate system. This will make it possible to assess the dynamics and energetics of quantomobile motion in a three-dimensional space in more detail, as well as compare such vehicles with other vehicles operating in this space, e.g. planes, helicopters, etc.

Conclusion

Based on the assumption of forthcoming introduction of quantum engines (QE) in the transportation industry, for the purposes of conceptual and theoretical training, the generalized force balance equation for a hypothetical quantomobile with five cases of its motion in the pitch plane was derived.

The vector approach to the force balance of a quantomobile distinguishes the derived dependences and their use from traditional force balance diagrams obtained in the classic automobile theory. The analysis revealed that it was possible to minimize the thrust for maintaining constant speed under the middle degree of vehicle suspension.

The authors believes that the derived generalized equation and brief calculations for a limited number of cases of uniform quantomobile motion can serve as an impetus for further studies in this area: analysis of other cases of quantomobile motion (pressing-down, breakoff from the bearing surface, optimization of the thrust vector use in variable motion modes, use of the lateral component of the thrust F_{Ty}, etc.). Naturally, the author's scheme may seem elusive since there are no technical (much less, statistical) data on quantomobile designs, but anything is possible.

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РЕАЛИЗАЦИЯ СИЛОВОГО БАЛАНСА КВАНТОМОБИЛЯ В ПЛОСКОСТИ ТАНГАЖА

Юрий Георгиевич Котиков

Санкт-Петербургский государственный архитектурно-строительный университет
2-ая Красноармейская ул., 4, г. Санкт-Петербург, Россия

[1] Email: cotikov@mail.ru

Аннотация

Введение: В преддверии внедрения квантовых двигателей (КвД) в транспортную отрасль небесполезно экспертное исследование свойств гипотетического автомобиля с КвД – квантомобиля. **Цель**: Осуществить расчетное исследование силового баланса квантомобиля и вариантов его движения в плоскости тангажа. **Методы**: Исходя из возможности генерации квантовым двигателем вертикальной составляющей вектора тяги (антигравитационной направленности) привлечен двухмерный подход к рассмотрению силового баланса квантомобиля. Сформировано обобщенное уравнение силового баланса для совокупности режимов движения квантомобиля в продольной плоскости тангажа. Выделено 5 характерных режимов движения. Выстраиваемые графические отображения являются частью совокупности аналитических действий, направленных на фиксацию и осмысление характерных граничных точек и кривых. **Результаты**: Реализованные численные примеры на базе названного уравнения силового баланса позволили интерпретировать режимы движения квантомобиля в плоскости тангажа, а также сформировать общую картину равномерного курсового движения квантомобиля. **Обсуждение**: Анализ выявил возможность минимизации величины траста для поддержания постоянной скорости в состоянии средней степени вывешивания экипажа. Сформированное уравнение силового баланса, отвечающее 2D-варианту движения квантомобиля в плоскости тангажа, может быть расширено до 3D-варианта движения этого экипажа. Это позволит более точно оценивать динамику и энергетику движения квантомобиля в трёхмерном пространстве, а также проводить сравнения с другими транспортными средствами, оперирующими в этом пространстве: самолетом, вертолётом и прочими.

Ключевые слова

Автомобиль, квантовый двигатель, квантовая тяга, квантомобиль, плоскость тангажа, силовой баланс.