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CAD/CAM/CAE-SYSTEMS IN DESIGN OF ARCHITECTURAL ENVIRONMENT

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Abstract. This article is about development prospects of **CAD/CAM/CAE-systems** and the significance of these systems for design of architectural environment. Modern technologies of designing are considered and practical examples of the architectural objects made by means and algorithms of **CAD/CAM/CAE-systems** are reviewed**.**

Key words: architecture, 3D-model, 3D-modelling, 3D-printing, **CAD/CAM/CAE-systems**, virtual reality.

1. Introduction

Every graphic system of 3D-modelling offers its own, often unique, object-building algorithm which is the main distinguishing feature of these systems. Each of these algorithms has been carefully developed and reasonably built; almost any problem can be solved with their help. In other words, the same object can be built in any 3D-modelling system, but in different ways. At the same time each algorithm is oriented to a narrower specialization, has a clearly expressed functional orientation and a large arsenal of opportunities in this segment. CAD/CAM/CAE-systems are the most effective technologies in design of architectural environment. In a general theoretical comprehension of specified question the works of the following researchers were used: K. Ulrich, S. Eppinger, Y. Suhanov, O. Efanov, Y. Bereza and other authors.

2. Basic theoretical section

In the scientific article a systematic approach helped consider the significance of CAD/CAM/CAE-systems, 3D-printing technologies and virtual reality in design of architectural environment has been used. The complex of the general scientific methods (historical-comparative and chronological, the method of terminological analysis) conduced to identify and consider the examples of practical application of specified CAD/CAM/CAE-systems in the architectural activity and design practice of the author.

3. Results and Discussion

CAD-systems (computer-aided design) [1] – computer support of designing. These systems are intended for the solution of design problems and registration of the design documentation. Leading three-dimensional CAD-systems allow implementing a full cycle of preparation and manufacture of difficult industrial products. **CAM-systems** (computer-aided manufacturing) [1] – computer support of manufacturing. These systems are intended for designing of product machining with computerized numerical control unit and issue of programs for unit. The three-dimensional model of a product detail created in CAD-system is used in CAM-systems. **CAE-systems** (computer-aided engineering) [1] – support of engineering calculations. The three-dimensional model of a product detail created in CAD-system is also used in CAE-systems which include engineering analysis as well.

CAD/CAM/CAE-systems occupy special position among other systems and represent the industrial technologies directed to the most important areas of product manufacturing. The impossibility of manufacturing

a difficult high technology production (companions, the ships, planes, tanks, cars, various kinds of machine tools and the industrial equipment, etc.) without CAD/CAM/CAE application is a generally recognized fact. The same situation concerns the architectural constructions and their complexes [2; 3].

One of the lines of CAD development is based on the creation and perfection of software conglomerate primary aimed at complete designing, manufacturing, running and recycling processes of any product. The completeness also includes objects structure designed and manufactured with special equipment as well as management of all technological processes, control of quality, packing, transporting and selling. Thus, CAD/CAM/CAE-systems become more and more universal in application to various design problems, and their computer toolset can be involved in architectural activity.

There is a considerable quantity of systems for architecture, interior design and building. All of them, to some extent, can solve the whole complex of questions connected with human environment: architecture, architectural constructions and architectural visualization; city planning, construction of roads; landscape design; building, including all engineering communications; design of interiors, in particular – public, decoration of premises, etc.

Fig. 1. Gym. First design version

Fig. 2. Gym. Second design version

Fig. 3. Gym. Third design version

The leaders in this sphere are such products as ArchiCAD (Graphisoft company) and AutoCAD (AutoDesk company). The second case is about software for architecture and building (AEC – Architecture, Engineering, Construction) – a complex of special CAD based on AutoCAD. The newest versions of ArchiCAD and Autodesk Architectural Desktop support the intellectual three-dimensional model of a building. However, a mass introduction of new architecture and building technology is hindered with the "inheritance" of two-dimensional files and paper drawings, which cannot be directly used in the intellectual model of building.

As an example of the architectural project designed in ArchiCAD environment, it is possible to consider the author's design decision of a gym for a private home ownership in Konche-Zaspa in Kiev. The total area of the gym is 176,5 sq. meters. Architecturally-planning decision consists of the central input with subsidiary premises and functional zones in the right and left wings of the building. In a central part of the building the sanitary-and-hygienic block is located, which includes the shower, bathrooms and mini-kitchen. In the left wing a gym with training equipment and a childish sports zone is provided. In the right wing the two rooms for visitors are planned. The design of form-building elements is based on a glass and metal combination. In the first design version a glass parallelepiped of a building with faceted structure of a facade is "pierced" with truss-shaped construction made of painted metal (Fig. 1). The second and third design versions are implemented with façade of a volume-spatial structure like a crystal rock. This is an elegant way to enter the gym into a natural landscape of Konche-Zaspa. The differences of these design versions lie in the artistic solution of entrance group, in the second design version the greatness realized as monumental boulder is underlined (Fig. 2). In the third design version the pathetic realized in pyramidal top, integrated into a building "body" is emphasized (Fig. 3). The structure of the entrance group is made of polished stainless steel and visually "disappears" in a surrounding space, and pyramidal top is a composition dominant.

Today the particular interest is represented by the projects on Revit platform. It is a system of a new generation from Autodesk, based on the most advanced concept of "Building Information Model" (BIM). This ideology has incorporated the latest achievements and technologies: as a matter of fact, it is a database and

imaging a design object. Drawing the levels and plans, over-heading and a roof, column and ladders placed in certain places accompanies with automatic data recording of these elements in the general database of the current project. Thus, all the elements of the model – the base, walls, roof, over-headings, windows, doors – are parametrically connected and coordinated. Revit being based on the parametrical core is capable to co-ordinate any changes in automatic mode: no matter, what part of the project is being worked by the user on – the model view, drawing sheet, specification, section, plan etc. It is possible to request all needed information referred to the current project, for example, views, sections, tables etc., which will be generated on the model of a building. Thus, the different ways of representation of database contents are applied.

Among the author's projects designed in the environment of Autodesk Revit, there is a modular set of seats for the architectural environment of Kharkiv. The necessity of the seats creation, which can be used in any city point, has predetermined the universality of the set and application of a modular design principle. The complete set of modular seats assumes some variations: single, double and three-place benches, turning modules for creation of l-shaped, s-shaped, u-shaped and other compositions, flowerbeds and urns, as the additional options of the benches. Each variation of the complete set, despite to the capacity degree consists of the following components: a concrete bearing, base made of stainless steel and bench sitting.

Fig. 4. Modular set of seats. Bus station

The width of a single variation of the modular set is 600 mm, double – 1200 mm, three-place – 1800 mm accordingly. The similar parameters provide convenience of sitting for people with different constitution and clothes when it goes about weather seasons. The depth of sitting is 480 mm, back slope is 15 degrees, height of armrests is 200 mm and all these values correspond to ergonomic requirements. The structure of the modular set of seats includes visible and invisible constructive elements. One of the visible elements of a modular set is concrete bearing with the slots for transportation and installation convenience, as well as centering cones for setting the right position of stainless steel base and fixing it relatively to the concrete bearing. The bearing contains weld-in armature necessary for the connection of bearing and base, and for fastening the bench sitting to the base.

Design of the complete set is based on a modular principle. A variety of components of the modular set allows to create different compositions depending on a district configuration and to add complementary options. It predetermines the universality of the modular set, its possibility to organize small bus station area in a form of narrow double bench (Fig. 4), and large park area with the creation of a big circular composition with the decorative flowerbeds (Fig. 5). Compositional expressiveness of the design solution of this set is based on a proportional combination of rectangular elements. The modular set was developed for the city environment of Kharkiv so the conception solution is close to the constructivism represented in many architectural monuments of our city. And though the conception solution of modular set has the certain lines peculiar to the constructivism, it also has a certain neutrality of shape. So, the application of this set in different city areas, for example, city streets or park-avenues is provided.

The CAD/CAM/CAE-systems are integrated with recent, but more and more popular direction of the 3D-printing generated by means of special printers. The 3D-printers are developed with the system of fast

prototyping (Rapid prototyping, RP) [2] – the technologies of the fast "prototyping", creation of pre-production model or working model of system for demonstration to the customer and control of the realization possibilities [4]. The technology of the 3D-printing gets the increasing popularity in an architectural activity, putting at new level the implementation and production of the separate elements of architectural constructions as well as the whole town-planning. A special cement structure for the 3D-printing, developed by the group of engineers of the British University of Loughborough, allows creating the constructive and decorative elements of various morphological configurations. Layer-wise building-up of enhanced cement structure facilitates a considerable simplification of construction works and the finished concrete products, if necessary, can be updated with painting and decoration [5].

The technology of 3D-printing "Contour Crafting" (author Berok Koshnevits) patented in the USA in 2009, assumes the printing of building structure "on a turn-key basis" in the near future. It means printing bearing structures with installed engineering communications, painted and decorated premises, the elements of the sanitary equipment and so on. The branch of South Californian University specially created by department of NASA is in process of realization of this project. Unlike futuristic "Contour Crafting", 3D-printer WinSun of Shanghai Company Shanghai WinSun Decoration Design Engineering Co is the pragmatic and utilitarian solution. WinSun represents the device with the overall dimensions of 10x40x6 meters, capable to print the house less, than for 24 hours [5], that is, developer's statement. The company portfolio has dozens of architectural and interior projects made with 3D-printing technology, thus, it is possible to assume that in future the 3D-printing will surpass traditional ways of building, and methodological bases of architecture will replenish with new algorithms of projects realization in an architectural activity.

Fig. 5. Modular set of seats. Parkland

As the example of complex object of design and architectural activity made by means of 3D-printing, it is possible to consider the design solution of metal bridge. A prototype presented by the Netherlands Company MX3D in autumn 2015. A distinctive feature of this company lies in its 3D-printing automatic manipulators with the tools for extruding and welding the metal, instead of traditional "boxes for printing", limiting the object overall dimensions. Thus, there is a possibility of free spatial manipulation in the course of creation of the form, its morphological structure and construction of different sizes [5]. For the today technology of the 3D-printing the direction in filling the body-spatial environment becomes more and more popular, passing from experimentally-pilot devices to the industrial complexes focused on industrial technologies of realization of design objects, architecture and town-planning.

The most interesting development prospect of CAD-systems, in an architecture context, is creation and perfection of the centers of a virtual reality for PLM. Product Lifecycle Management – is the process of managing the entire lifecycle of a product from inception, through engineering design and manufacture, to service and disposal of manufactured products [6]. Virtual reality technologies are used in design of complicated system products (aircraft, cars etc.); visualization of complex architectural solutions; planning of urban development (urban planning); that is where the concept development needed, coordination of components and, even, testing (up to reception of virtual operating experience) should be spent long before the stage of a physical prototype creation. The systems of virtual reality (immersion centers, lat. *Immersio* –

immersing) are also used for effective demonstrations to the persons – decision makers: investors, customers, focus groups of experts, etc [7].

By the same principles can be developed architectural designing and modelling, when a special system software: Autodesk Revit, ArchiCAD, Autodesk AutoCAD architecture and other software packages are integrated in VR, thus, there is a possibility of interactive virtual prototyping of cities, areas, buildings and interiors in real scale with the subsequent 3D-visualisation of the design data. A special efficiency of application of VR technology can be shown in the process of adaption of architectural construction/complex with the personified city environment that is one of the main, defining architect's tasks. VR technology allows estimating the designed building from those or other foreshortenings of a district landscape and on the contrary assists in consciousness of the reality from a projected construction.

Thus, the development prospects of CAD/CAM/CAE-systems assume full integration with a virtual reality. In other words, the complete set of the software delivery basically will include "immersion module", with the corresponding equipment (helmets of a virtual reality, 3D-points, gloves with the tactile sensors, special joysticks, etc.). With their help projector can adapt designed object in the corresponding environment. The architect, for example, can "put" the designed building in the urban environment of Kharkiv, in 77, Sumskaya Street, and virtually estimate the real merits and demerits of the exterior walk round of the construction on perimeter, and visit floors and premises of the interior. These technologies are the future of the design process.

The phenomenon of the digital revolution formed the basis for the prevailing majority of innovative developments in various spheres of human life, including architecture and design. These include CAD/CAM/CAE-systems, technologies of 3D-printing and virtual reality, as well as other innovative processes that, in the current globalization and post-industrial economy, are a strategic resource for the development of architecture and design. The variety of these developments and the rapid pace of their implementation determine the necessity to clarify and specify the innovations in the context of interdisciplinary interaction of architecture and design. This process is aimed at the formation of project-methodological base that can integrate such technologies into the profession, apply them as design principles and predict their results.

4. Conclusions

The CAD/CAM/CAE-systems combined with the technologies of 3D-printing and virtual reality open a lot of new design possibilities of creation design ideas and their effective implementation in application to architectural activity and design practice. Given in the scientific article examples, supported with the appropriate theoretical studies, illustrate the convergence of technologies and design achievements from various industrial sectors. The variety of professional software and its rapid development must be mentioned as well, in some cases – the subsequent transformation into the new innovations, in others – the disappearance from the scientific field, both temporary and final. Therefore, further clarification of these processes is necessary, as well as determination of their structural components and formulation of application algorithms in architectural and design practice, which requires theoretical comprehension, scientific analysis, reasoned conclusions and approbation in the design process.

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CAD/CAM/CAE-СИСТЕМИ В ДИЗАЙНІ АРХІТЕКТУРНОГО СЕРЕДОВИЩА

Анотвція. *CAD/CAM/CAE-системи займають особливе положення серед інших систем, оскільки представляють індустріальні технології, безпосередньо спрямовані на найбільш важливі області матеріального виробництва. Сьогодні загальновизнаним фактом є неможливість виготовлення складної наукомісткої продукції (супутників, кораблів, літаків, танків, автомобілів, різних видів верстатів і промислового устаткування і ін.) без застосування CAD/CAM/CAE-систем, не кажучи про архітектурні споруди та їхні комплекси.*

Один із напрямків розвитку CAD/CAM/CAE-систем ґрунтується на створенні і вдосконаленні програмних конгломератів, основне завдання яких полягає в забезпеченні повністю завершеного процесу розробки, виготовлення, експлуатації та утилізації будь-якого об'єкта. Само собою зрозуміло, що до питань завершеності належать розробка конструкції об'єкта і оснащення для його виготовлення, управління всіма технологічними процесами при виробництві об'єкта, контроль його якості, упаковки та транспортування, а також його реалізація. Таким чином, CAD/CAM/CAE-системи стають усе більш універсальними в застосуванні до різних проектних завдань, а наданий ними комп'ютерний інструментарій може бути задіяний в архітектурній діяльності.

Найцікавішою перспективою розвитку CAD/CAM/CAE-систем, в контексті архітектури, є створення і вдосконалення центрів віртуальної реальності для PLM (Product Lifecycle Management). Технології віртуальної реальності використовуються при проектуванні складних системних продуктів (авіація, автомобілі тощо) для візуалізації комплексних архітектурних рішень, при плануванні розвитку міст (urban planning), тобто там, де розроблені концепції, ув'язка компонентів і навіть тестування (аж до отримання віртуального досвіду експлуатації) повинні бути проведені задовго до етапу створення фізичного прототипу.

Отже, особлива ефективність застосування технології VR проявляється в процесі пристосування архітектурної споруди/комплексу з персоніфікованим міським середовищем, що є однією з головних, визначальних завдань проектанта. Це дозволяє оцінити, як сприймається спроектована будівля з тих чи інших ракурсів ландшафту місцевості і навпаки, сприяє усвідомленню дійсності з проектованої споруди.

Ключові слова: *архітектура, 3D-модель, 3D-моделювання, 3D-друк, CAD/CAM/CAE-системи, віртуальна реальність.*