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REVIEW PAPER

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VISUALISATION IN ARCHITECTURE – OPPORTUNITIES AND THREATS

Grzegorz Glinko✉

Faculty of Engineering, Helena Chodkowska University of Technology and Economics, Warsaw, Poland

ABSTRACT

The development of computer technology, the computing power of graphics cards and processors, and the use of appropriate software allows us to create extremely realistic three-dimensional images. The effects of the generated visualisations can be difficult to distinguish from real photos of objects. Architects often verify the fulfilment of design goals based on a rendered digital image. Unfortunately, designers are often not fully aware of the limitations and simplifications of the tools used to create these visualisations. An uncritical approach to the presented results may lead to various design errors. This article presents the possibilities of visualisation in selected computer programs used by architects, and cases in which correct visualisation is possible only through the use of specialised software. The article also pays special attention to the possibility of errors in the visualisation of architectural lighting.

Keywords: architecture, 3D visualisation, Photopia, architectural lighting, visualisation in architecture

INTRODUCTION

Three-dimensional visualisation has a vast future ahead of it, and it is continuously evolving. This is particularly evident in the fields of architecture and interior design. The graphic and simulation capabilities of computers are already significantly influencing the way houses are built, the design and production process, error elimination, and, of course, the overall project completion time. The development of collaborative digital platforms allows for the exchange of ideas and data, enabling designers from related disciplines to engage in shared and efficient engineering (Glinko, 2022). This article presents various possibilities for creating 3D visualisations, focusing on the capabilities and limitations associated with visualisation in architectural lighting. Visualisation can significantly reduce the costs and time spent on field testing with numerous illuminators, as well as the analysis of lighting solution variants and concepts.

In such applications, visualisation serves as a crucial element in confirming the correctness of the design concept. Creating accurate visualisations requires an understanding of the limitations and capabilities of the employed 3D visualisation software. These limitations may arise, for example, from the construction of the light source model or the definition of the optical properties of the materials. Architectural software introduces certain simplifications that can lead to significant errors in some cases. In this regard, it is necessary to use specialised software for designing optical systems, such as Photopia. Fortunately, software manufacturers increasingly allow the utilisation of these specialised tools within familiar architectural software platforms,

Grzegorz Glinko https://orcid.org/0000-0002-9598-326X
✉grzegorz.glinko@uth.edu.pl

like Rhino or SolidWorks. This not only enables designers to work in a familiar environment but also facilitates the creation of highly accurate visualisations in atypical lighting situations. Examples of the need for specialised tools include simulating the light distribution below the photometric measurement threshold distance or mixing colours of light from sources with different colour temperatures. Additionally, designers can benefit from the built-in parametric design functions of the software, enabling them to create unique and individual shapes. An example of this is the integration of Photopia with Rhino software.

VISUALISATION IN ARCHITECTURE

Three-dimensional visualisation is the process by which graphic content is created using 3D software. Such terms like 3D rendering, computer generated imagery (CGI), and 3D graphics are associated with the concept of visualisation. In recent years, 3D visualisation technology has been implemented in many industries to present high-quality graphic content, influencing better communication, increasingly real digital experiences and the visual verification of proposed design solutions.

The main industries associated with visualisation techniques include:

– product design, manufacturing and presentation,
– architecture and interior design,
– media and entertainment.

Architecture uses various visualisation methods, while designers use both 2D visualisation and spatial visualisation. Spatial visualisation makes it possible to depict the designer's work much more accurately, while three-dimensional visualisation is becoming an indispensable part of architectural designs. At the same time, the forms of spatial visualisation are evolving from static to dynamic visualisation, while a relatively new trend is interactive visualisation.

Static visualisation methods make it possible to present a project from the specific perspectives chosen by the designer. An example of a simple static visualisation is shown in Figure 1, a visualisation of one of Warsaw's housing estates.

Dynamic visualisation, or animation, makes it easier to understand the spatial relationships between the designed objects. Often, in addition to the image itself, designers add an audio background. Interactive visualisations allow the use of modern design presentation techniques, such as a virtual walk-through. The client can decide on his own in which direction they wish to move and from what perspective to observe the digital reality. In summary, 3D visualisation is a form of graphical representation of reality, which allows you to become acquainted with the object at any stage of its design. In this way, visualisation provides a platform for communication with the client, which allows verification of the design assumptions during the design process. The aspects presented in the visualisation may concern both technical and aesthetic matters. Modern software can combine visualisation techniques along with simulation tools, while also monitoring the design process and alerting us to the emergence of certain design risks and constraints. The following examples illustrate the possibilities of supporting the designer in the process of realising 3D visualisations in selected CAD programs.

Specialised computer programs make it possible to create a virtual model of an object from a photo. Creating a spatial object from a photo, with manual modelling, is typically a rather time-consuming process; however, volumetric design software is able to use appropriate algorithms to generate the 3D models while also continuing to strongly increase the development process.

These involve not only simple buildings, but also faces and figures. Visualisation software may also include photogrammetry software, which allows the creation of 3D models from a series of 2D images or photos taken from different angles. Figure 2 shows the process of creating a 3D model of a tenement house on Wąski Dunaj in Warsaw's Old Town, using a previously taken photograph. The spatial model of the tenement was created using SketchUp software, while the reproduction was achieved through manual modelling technique using the photo matching function.

Fig. 1. Static visualisation of a housing estate in Warsaw

Source: own work.

Fig. 2. Illustration of the process of creating a three-dimensional model of a tenement house from a photo. The tenement house is located in the Old Town of Warsaw. SketchUp software was used to create the building model, while the digital model was made using a hand modelling technique

Source: own work.

Light and its reaction with materials play a key role in the correctness of the visualisation of spatial effects. The degree of realism of the perception of the modelled objects, therefore, depends on the correctly defined optical properties of the materials and properly created models of the light sources. Often, when it is necessary to obtain real illumination distributions on illuminated surfaces, architectural software may be insufficient. Correct visualisation requires the use of additional specialised simulation tools. On the software market there is currently a trend to transfer the capabilities of specialised programs to architectural or engineering software in the form of plug-ins. One example of this is Photopia software from an American company, LTI Optics. This company specialises in software for simulating light distribution and supporting designers in modelling such optical systems as reflectors, lenses, prisms, scattering glasses, etc. Due to the interdisciplinary nature of many engineering disciplines, they decided to implement its software into Rhino and SolidWorks. This new approach to software implementation methods increased not only the simulation capabilities of the software for which the plug-ins were prepared, but also of Photopia itself. An additional advantage is the ability of designers to work in a familiar software environment (LTI Optics, 2022).

The developers of architectural lighting software, such as DIALux and Relux, are increasingly developing the ability to visualise and import textures, spatial models and objects made in other design programs. DIALux can also, through its data management system (DMS), import industry foundation classes (IFC) files, which are open format files used by building information modelling (BIM) programs. Industry foundation classes files can contain information about a building or facility model, including the spatial elements, materials and shapes, but they also contain data about lighting fixtures, e.g. luminaire model, photometrics, mounting type, weight, etc.

Figure 3 shows a visualisation of the interior lighting of an apartment made with DIALux evo software. The visible light fixtures are all models based on photometric data. The ability to use real luminaires with EULUMDAT-type data in the simulation, in which the light distribution information is stored, provides the possibility of a much more accurate analysis of the light distribution in space. Such a capability is usually not available in the typical interior modelling programs used by architects.

Fig. 3. Interior lighting visualisation of the flat made with DIALux software

Source: own work.

Three-dimensional visualisation software plays a significant role in architecture and interior design by accelerating and improving the work process in this sector. Three-dimensional visualisation technologies enable the development of cooperative and digital engineering, the quick production of design elements, the reduction of errors throughout the design process, and the presentation and handling of projects. The client has the opportunity to see the near-final digital result of the project, before starting work on it. In the case of architecture and interior design, 3D visualisation gives clients the opportunity to see the building layout, interior and exterior designs, lighting, textures, etc., before completing the development process.

To the visualisation methods already described we can add the latest visualisation techniques related to virtual reality (VR) and augmented reality (AR) technologies. Taking advantage of its capabilities requires an additional item, such as VR goggles. After placing the VR goggles on our head, our entire field of vision is filled with an image from the virtual world and we can observe any part of it by simply turning our head. This technology also allows movement and the exploration of space, with the only limitation being the size of the world modelled by the designer. Movement in the virtual reality is controlled with the hands, using special controllers, while more advanced equipment allows mapping of the movements of the entire human body.

Augmented reality is a technology that involves overlaying virtual 3D objects, generated in real time, onto images in the real world, using image-processing, and so allowing architects to simplify the design process. It is an advanced form of design visualisation, which allows one to understand the results of a project and its impact on the environment before incurring the costs of implementation. Augmented reality also makes it easier to locate errors and, as a result, contribute to saving time and reducing the investment costs.

CHARACTERISTICS OF SELECTED TOOLS FOR THREE-DIMENSIONAL SIMULATIONS WITH VISUALISATION

Computer software manufacturers have created a wide range of applications intended for architects, some of which are well established in the market. The designer, regardless of whether they are working on a product, interior design, building or landscape architecture, expects visualisation capabilities from their software. Among the most commonly used CAD programs today are:

- SolidWorks, mainly used in the product development process by mechanical, electronic and electrical engineers. This software is able to support designers in the construction of tools and equipment, including injection moulds, stamping dies, workstation equipment, auxiliary equipment, etc. It also allows assembly models and technical drawings to be made, while due to the possibility of adding additional software, known as plug-ins, the operation of the program can be extended with specialised simulation tools, such as the simulation of optical systems and the simulation of lighting effects for motion and loads. The program is also used by architects for specialised design tasks.
- SketchUp, which is a relatively easy-to-use 3D modelling and design program. It provides a set of tools that allow quick spatial modelling and texturing, while the extensive editing functions allow you to change the already existing materials. You can create your own objects or work on objects imported from the 3D warehouse. It also has many free tools to support the process of building 3D-models and also includes defined light models that can be used to illuminate the arranged space, while to increase the realism of the presentation it is possible to use external engines for rendering images (Pasek, 2011).
- Lumion is a program created for the visualisation and animation of architectural objects. It allows the quick and easy generation of high-quality renderings. The developers of the program offer a five-step visualisation process: import the project, add materials, create the environment, add objects, apply effects and render them.
- Rhino (Rhinoceros) is a program that includes specific features and tools for free 3D modelling. The latest version of the program (Rhino 7) allows the use of physically based rendering (PBR) type materials, which, according to the manufacturer, enable high-quality realistic renderings. This type of graphic material is becoming a standard for material libraries, creating content for scanning that is supported in many modern applications. Rhino allows the creation, editing, analysis, documentation, rendering and animation of three-dimensional objects. It is very often used in product visualisation, while external software, such as Photopia, can be attached, which is able to perform very accurate lighting simulations including the simulation of light colour mixing with visualisation.

The program has a unique Grasshopper plug-in, responsible for algorithmic (parametric) modelling. This allows you to design and edit complex shapes using specific parameters, and in the expanded version with Photopia software and the Grasshopper function it is able to create unique models of lighting fixtures and carry out detailed visualisation and analysis of the light distribution on such a designed product.
- AutoCAD comes in many versions designed for various design tasks. One of them is the version with the Architecture toolkit, which includes several thousand architectural components, functions for the automatic generation of objects, elements such as walls, doors and windows with stored information on their actual behaviour and construction, as well as a number of other solutions to support the work of the architect.
- DIALux software is used to design complex architectural lighting, industrial facility and outdoor area lighting, including for roads and streets. The program is able to calculate daylight in clear or overcast skies and take into account daylight systems. DIALux has its own library of materials and objects, which can be expanded with materials created externally in CAD software. DIALux also allows the detailed presentation of lighting results in the form of luminance or illuminance distributions. Figure 4 is an example of the visualisation of the luminance distribution in the room presented in Figure 3. The luminance distribution is shown using false colours. Using this form of visualisation, the designer can verify that the resulting lighting effects are not characterised by too much difference in luminance contrast in workplaces, for example, which may cause excessive glare (Immecke, 2021).

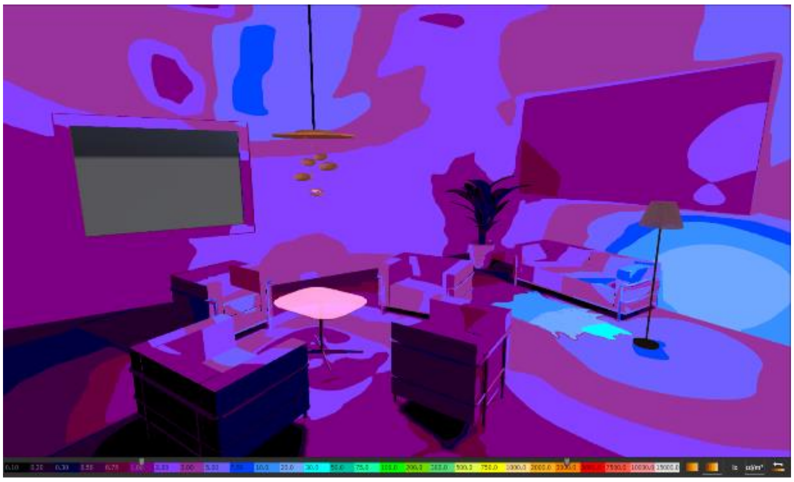

Fig. 4. Visualisation of luminance distribution in an apartment depicted with false colours, made with DIALux evo software

Source: own work.

SOFTWARE SIMULATION LIMITATIONS AND THEIR IMPACT ON VISUALISATIONS

Lighting can form a critical component of any architectural project. In some cases, there is a need to obtain very precise information about the visualisation of the light distribution on the illuminated surfaces. As mentioned earlier, designers are often unaware of the simulation limitations of the tools they use in visualisations. They mistakenly assume that the generated image will be close to the actual lighting effects. Most of the programs commonly used by architects are unable to correctly simulate colour mixing in a lighting fixture, spectral effects, or lighting of structures from a short distance. The correctness of such visualisations can only be provided by specialised software based on light distribution calculations using the Monte Carlo methods or inverse ray analysis. An example of a program in which it is possible to perform highly complex analyses of light distribution, in complex optical systems, using real models of light sources, is Photopia software. The manufacturers of this software, after analysing the market, decided to prepare a plug-in for Photopia's version software for SolidWorks and Rhino. This allows the different software to increase their analysis and computer simulation capabilities, and designers to remain in their familiar working environment (Krupiński, 2011).

Figure 5 shows the imaging of spectral effects in architectural lighting. The example shows the lighting effect of a luminaire with randomly modelled holes in the reflector. The luminaire is equipped with blue, red and green LEDs. The diodes are arranged in the luminaire in various locations, resulting in shifted coloured light patterns emitted through the holes. The light from the interior of the lamp can leave the shade directly or mix with other colours due to multiple reflections inside the fixture. Such effects cannot be simulated properly with standard software. A Voronoi pattern, generated using the Grasshopper function available in Rhino software, was used to create the holes (Glinko & Jongewaard, 2022).

Fig. 5. Visualisation of light distribution considering the spectral distribution of light sources in a room illuminated with a luminaire with blue, red and green LEDs

Source: LTI Optics, LLC, Photopia™ for SolidWorks & Rhino Architectural Lighting, LTI Optics, LLC. 2022.

Most computer software is not able to properly visualise the illumination of structural surfaces from a short distance. Even DIALux software, which relies on EULUMDAT-type photometric data, cannot function in this case. This is related to the way that photometric solid models are built, in which the luminaire has a measured light distribution with a limiting photometric distance (LPD). Illuminating objects from a short distance requires the use of tools that can perform the analysis below the LPD. From this point of view, a properly made model of the light source is also important. Usually such models are very simplified, and their shape is similar to basic spatial solids, such as cuboids or cylinders. Most often, the light in these models is emitted uniformly from their entire surface, which in some situations is far from reality. Figure 6 shows a correct visualisation of structural wall lighting made using Photopia software in the Rhino environment.

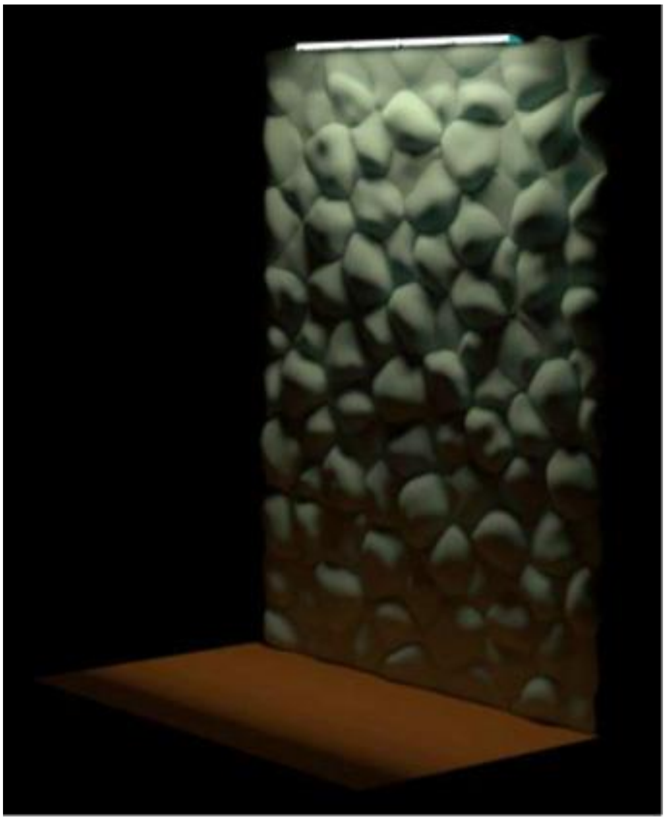

Fig. 6. An example of the proper visualisation of the light distribution on a structural wall. The visualisation was made using Photopia software in the Rhino environment

Source: LTI Optics, LLC, Photopia™ for SolidWorks & Rhino Architectural Lighting, LTI Optics, LLC. 2022.

Visualisation errors can also be influenced by the actual design of the models of reflective surfaces, such as walls, ceiling and floor. Architectural lighting programs often treat them as perfectly diffuse reflective materials. The effects of reflections and directional reflections seen in renderings are approximate and are the result of single-pass ray tracing at the end of the image generation process.

The accuracy of the visualisation is particularly important for object illumination. A properly performed visualisation allows us to verify design variants, to check the correctness of the design process at various stages, and to reduce the potential costs associated with the resulting errors and the need to correct them during the project implementation process.

To sum up, it should be added that artificial intelligence (AI) is an increasingly common tool used in visualisations, including in architecture. There are increasing numbers of tools and programs using AI modules appearing on the market. Creating photorealistic images of interiors using AI is simple and not time-consuming, it creates enormous opportunities, but at the same time it brings additional threats, related not only to incorrect light reproduction. In the long run, AI tools may change the picture of the labour market, the structure of employment process, the pricing and the availability of services. One example of the use of AI in visualisation is shown in Figure 7, based on the visualisation made by DIALux evo software in the computer simulation process shown in Figure 3.

Fig. 7. An example image generated with the help OpenArt, using the high creativity of the proposed solutions

Source: own work.

The visualisation was made using the OpenArt tool, which allows multi-variant creation of images based on previously provided photos or renderings. Entering additional text (prompting) is possible, but not obligatory. The user can control the colours of the generated images and their degree of similarity to the original.

CONCLUSIONS

The market for 3D visualisation technology continues to grow significantly every year, covering ever more areas of our lives. The advertising industry (digital advertising) and 3D animation are increasingly using visualisation, the technology and popularity of printing objects on 3D printers is also growing, and it seems that in the coming years the processes related to visualisation capabilities will accelerate even more strongly. Increasingly, software manufacturers are introducing visualisation software into their ranges, one example being Adobe, which recently introduced the Substance 3D Collection suite of tools for creating, recording and editing 3D materials and textures, to help building and rendering 3D scenes. The ever-expanding capabilities of engineering computer software and the ability to transfer data to various computer applications are greatly accelerating the design processes. In this aspect, it is worth noting the increasingly popular building information modelling (BIM) system, which is already the foundation of digital transformation in the architectural, engineering and construction industries. Every piece of software has its limitations and may use simplifications, and these limitations can also be related to the accuracy of the visualisation. Executing the project according to the expected final result requires knowing and understanding these limitations and, in special cases, using additional specialised software.

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WIZUALIZACJA W ARCHITEKTURZE – MOŻLIWOŚCI I ZAGROŻENIA

STRESZCZENIE

Rozwój technologii komputerowej, mocy obliczeniowej kart graficznych i procesorów pozwalają, przy wykorzystaniu odpowiedniego oprogramowania, na kreacje niezwykle realistycznych trójwymiarowych obrazów. Efekty wygenerowanych wizualizacji mogą być trudne do odróżnienia od rzeczywistych zdjęć obiektów. Niejednokrotnie architekci weryfikują spełnienie celów projektowych, wykorzystując do tego wyrenderowany obraz cyfrowy. Niestety często projektanci nie są w pełni świadomi ograniczeń i uproszczeń, jakie niesie ze sobą stosowanie narzędzi do tworzenia wizualizacji. Bezkrytyczne podejście do prezentowanych wyników może prowadzić do błędów projektowych. Niniejszy artykuł przedstawia możliwości realizacji wizualizacji w wybranych programach komputerowych wykorzystywanych przez architektów oraz przypadki, w których poprawna wizualizacja jest możliwa jedynie przy zastosowaniu oprogramowania specjalistycznego. W artykule zwrócono szczególną uwagę na możliwości powstawania błędów w wizualizacji oświetlenia architektonicznego.

Słowa kluczowe: architektura, trójwymiarowa wizualizacja, Photopia, oświetlenie architektoniczne, wizualizacja w architekturze