Budownictwo i Architektura 22(1) 2023, 5-14
DOI: 10.35784/bud-arch.3327
Received: 28.11.2022; Revised: 28.02.2023;
Accepted: 03.03.2023; Available online: 30.03.2023

Orginal Article

Use of applications and rendering engines in architectural design – state-of-the-art

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Abstract: Computer methods in the AEC (Architecture, Engineering, Construction) industry are constantly evolving, mainly towards BIM, and the design process itself within an investment project focuses mainly on documentation. Visualisation or animation are optional elements, mostly done for sales purposes. Photorealism and the quality of created visualisations influence the impressions of the recipient, and the emotions evoked can determine a purchase or investment. As a rule, designers pay great attention to the visualisations they create, but they are not always aware of the solutions available on the market in this respect. In recent decades, rendering engines based on so-called real-time rendering have developed rapidly. The aim of the study was to provide a deep review of existing 3D modelling and visualisation solutions in terms of their popularity, applicability and advantages and limitations. The focus is on applications working with BIM software, which is widely used in the AEC industry. The paper attempts to compare the applications, lists their advantages, disadvantages, benefits and limitations in their use. The conclusions, sometimes subjective, can be useful for the whole community of architects and engineers, related to space design. The results of the review indicate the increasing popularity of 'real-time' solutions, which are displacing 'offline' solutions.

Keywords: building information modelling; BIM application; visualisation software; real-time rendering; AEC industry

1. Introduction

Rendering, which can be defined as the process of generating an image based on a specific computational model, is an integral part of creating visualisations. Otherwise rendering is the graphical representation of digitally stored content in an environment-specific form (e.g. display on a computer screen). The part of a computer program responsible for rendering is the rendering engine or renderer. Currently, we can distinguish two approaches used in computer graphics for their preparation: the so-called offline and real-time rendering. The former is a process associated with the traditional path, where

the works performed are extremely detailed and present a look close to photorealism, e.g. thanks to the faithful representation of lighting [1]. However, due to the large number of calculations performed at one time and the considerable hardware requirements, the creation of a single frame through the rendering process itself can take many hours. This excludes the aspect of interactivity, which is the main advantage of the latter approach taking place in real time - where the images displayed on the screen are generated, for example, at a rate of thirty per second. Hence the growing popularity of the 'real-time' approach. Real-time rendering is the process of generating visualisations in a synchronous manner and therefore quick and simple to edit.

Combining the visualization of BIM (Building Information Modelling) with Augmented Reality (AR) offers unlimited possibilities. The prerequisite for the use of AR is the development of suitable applications for mobile devices such as smartphones or tablets, for real-time visualization of 3D digital designs. With AR, we can transfer selected objects such as houses, building elements or interior finishes from the virtual world into the real world using the video stream of mobile devices [2]. There are at least several definitions of visualisation in the literature. In order to define visualisation in an unambiguous way, it is necessary to refer to the purposes for which it is used. In the simplest terms, it can be considered as "the act or process of interpreting a space" [3] and then converting it into a graphic form. It is commonly used as a tool to present designs [4] or concepts, although it can also be important when trying to predict the final appearance of an object before it is realised. It is a kind of bridge between the authors of the plan and the final recipient - client or user - allowing more effective communication. Those unfamiliar with the details of producing technical documentation can make comments by viewing the 3D model or reviewing the non-graphical information (Fig. 1).

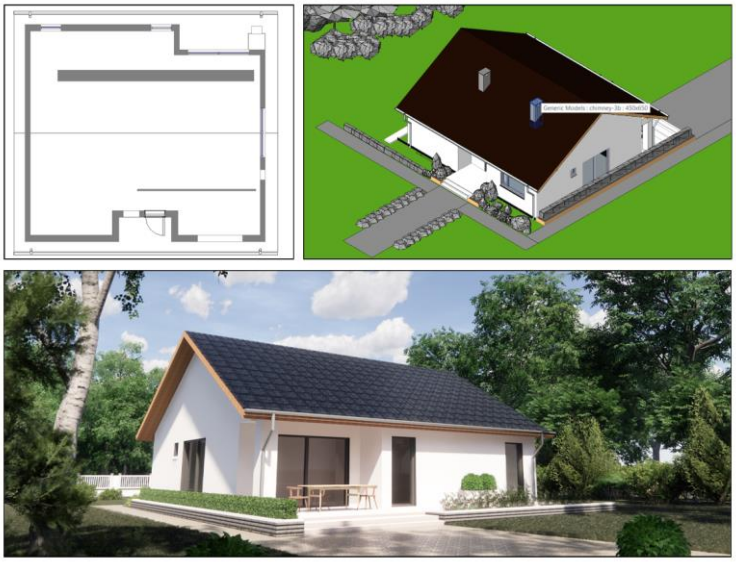

Fig. 1. Comparison of two different views on single-family house design. *Source:* own elaboration.

2. Advantages of computer visualization

In late 20th century, architects and engineers stopped using traditional drawing and calculation tools in favour of CAD and later BIM systems [5]. Although individual works drawn with a pencil and depicting a given perspective are still popular due to people's attachment to classical techniques and originality of style, they have been superseded over the years by digital projects as a result of several factors. The first of these is related to costs - specialistic software for commercial use can be expensive, but taking into account the final result and time savings (e.g. by not having to draw each perspective change from scratch), the costs of creating such visualisation for companies are much lower. Apart from the speed of the whole process, an undoubted advantage is also the possibility to introduce changes on the fly and test many variants simultaneously. BIM streamlines the process in terms of the time taken to complete selected tasks, as well as the use, transfer and management of information [6]. With BIM technology, three-dimensional models of existing objects are obtained at different scales [7]. The use of three-dimensional models makes it possible to work with a project at several different stages of its implementation - from initial concepts to more detailed solutions, to have a chance to eliminate potential difficulties. Another advantage of the digital form over the paper form is the visualisation and animation aspect, which allows to present the interiors and surroundings in a more vivid and richer way than in the traditional form. Visualisation and animation tools can be directly linked to the design software, can be installed in the form of "computer farms" - i.e. several regular computers in the same workplace, or they can be made available as a service (Software as a Service). Sophisticated visualisations, fly-through animations or AR (augmented reality) support the decision-making process throughout the investment cycle [8].

3. Commonly used software

In relation to the whole visualization process, two types of computer programs should be distinguished - packages used to create geometry, textures and lighting in the whole scene (e.g. 3ds Max) and those using the above mentioned components to create the final image based on a special algorithm or procedure, known as rendering engines. Most often they are integrated with each other within a single product through plug-ins or extensions or, much less often, they work as two independent applications [9]. Due to the fact that there are currently dozens of different products on the market in which projects can be created, also rendering engine manufacturers offer their dedicated versions for multiple platforms simultaneously (Tab. 1).

Table 1. Official availability of rendering engines for design applications. *Source:* Own elaboration.

Software / rendering engine	Revit	3ds Max	Cinema 4D	Sketch Up	Blender	Rhino	ArchiCAD
Unreal Engine	✓	✓	✓	✓	✗	✓	✓
V-Ray	✓	✓	✓	✓	✓	✓	✗
Corona	✗	✓	✓	✗	✗	✗	✗
Enscape	✓	✗	✗	✓	✗	✓	✓
Lumion	✓	✓	✗	✓	✗	✓	✓
Octane	✓	✓	✓	✓	✓	✓	✓
Internal rendering engine	✓	✓	✓	✗	✓	✓	✓

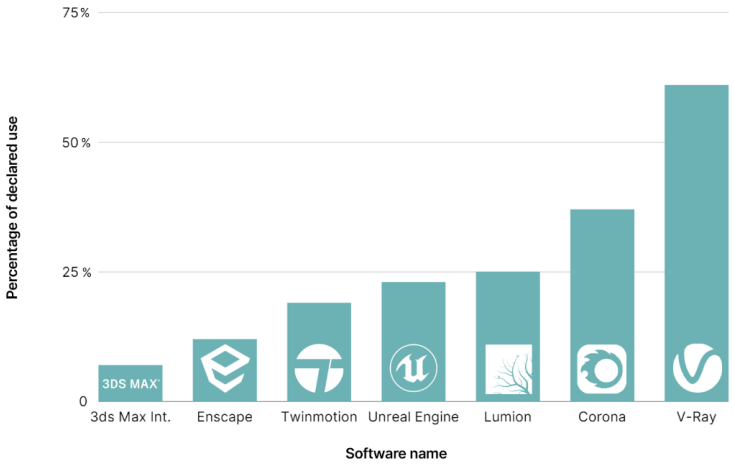

Fig. 2. Popularity of rendering engines among designers in 2021. *Source:* own elaboration.

It is worth noting that in the same ranking, but in a different category (most commonly tested solutions in design studios), engines such as Unreal, Enscape and Lumion are at the top of the table (Fig. 3). Among the most popular solutions, dedicated extensions prepared specifically for BIM-type applications support about half of them, while the process of representing scenes in the remaining ones is sometimes difficult, although not impossible.

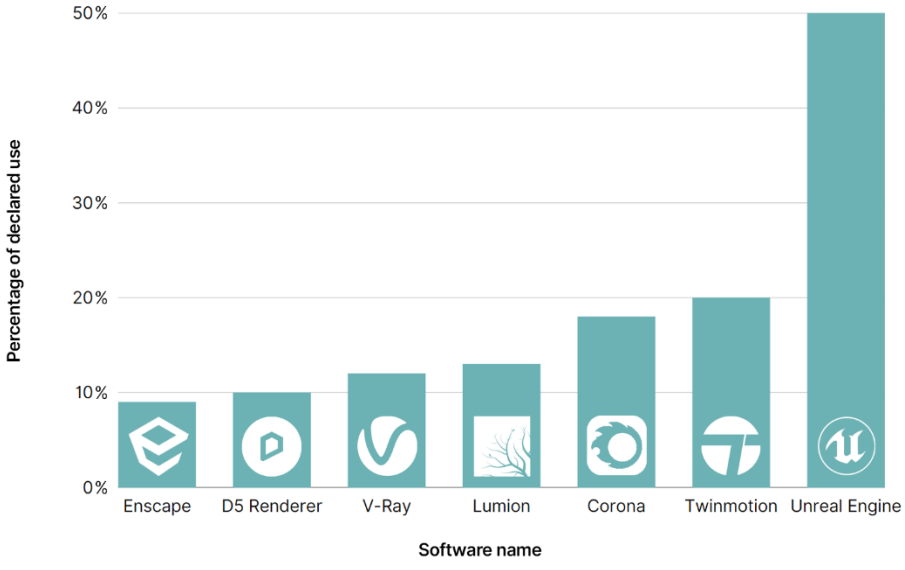

Fig. 3. The most tested rendering engines among designers in 2021. *Source:* own elaboration.

Various organisations have conducted studies on the popularity of using applications in the development process. Visualisation software is used by many professions and industries. On the basis of studies conducted by Chaos Group [10] and NBS (National Building Specification) [11], it can be concluded that programs frequently used for design purposes are, for example, SketchUp, 3ds Max or Revit (Fig. 4).

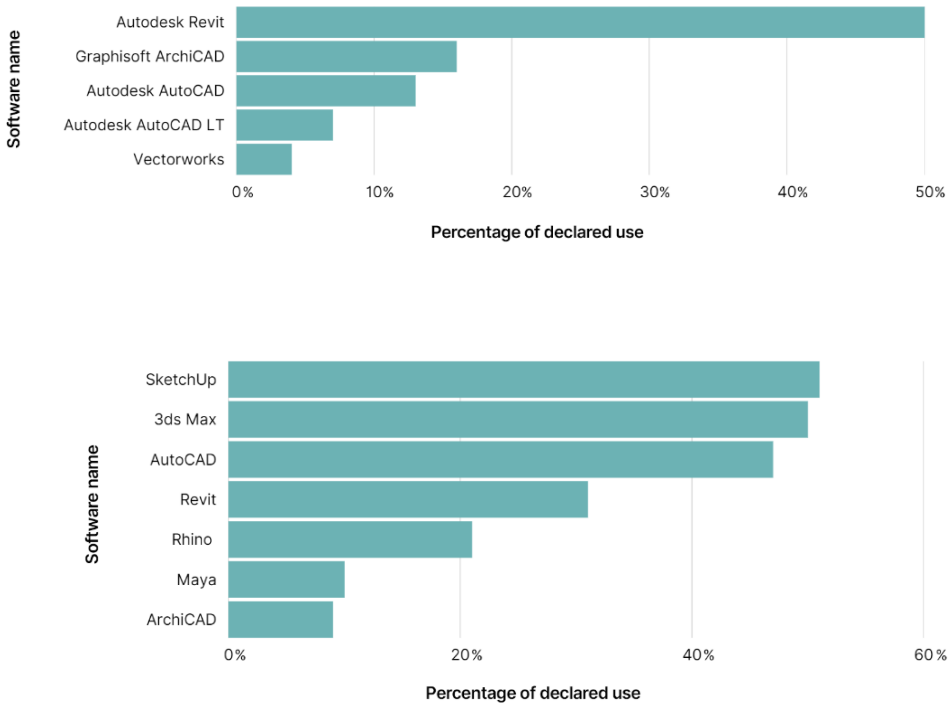

Fig. 4. Popularity of project applications according to NBS report (top chart) and Chaos Group (bottom chart). *Source:* own elaboration.

The multitude of software choices also translates into a very large number of available versions and their distribution models. For example, access to rendering engines is sold as a monthly or annual subscription, or more traditionally, as a so-called perpetual licence, which translates into different product prices depending on their version (Tab. 2). In addition to licences aimed solely at sales aspects, most manufacturers (Enscape, Act-3D, Chaos) offer free versions for students to use for educational and non-commercial purposes.

Table 2. Prices of rendering engines in various forms of sale in PLN (1 EUR = 4,7 PLN) (state as 26.06.2022). *Source:* Own elaboration.

Company/name		Monthly	Yearly	Perpetual license
Act-3D	Lumion Standard	-	-	7 048,00
	Lumion Pro	-	-	14 102,00
Epic Games	Twinmotion	-	-	2 215,56
	Unreal Engine 5	-	-	Free
Otoy	Octane Render Studio	93,96	198,96	-
Maxon	Redshift	211,56	1 242,30	
Blender Foundation	Eevee	-	-	Free
	Cycles	-	-	Free
Solid Angle	Arnold Renderer	222,00	1 672,00	-
Enscape / Chaos Group	Enscape	187,53	2 250,36	-
Chaos Group	V-Ray 5	258,50	1 480,50	3 337,00
	V-Ray 5 Educational	37,60	418,30	-
	Corona Renderer	187,00	1 316,00	-
	Corona Educational	-	188,00	-

4. Use of BIM in visualisations

Models and scenes made in BIM technology are now increasingly appreciated in the field of interactive visualisation due to the possibility of storing a large amount of information [12]. One of the reasons for this is the fact that parametric modelling makes it much easier to change and edit individual objects added to a scene on an ongoing basis than would be possible with a traditional approach [13]. Visualization, which is created through the rendering process, based on a three-dimensional digital model of a space or a city with its transport infrastructure and all building structures can become a tool in the public participation process. Building digital spatial models is a challenge for many communities [14]. Public and private clients are increasingly demanding dynamic forms such as animation, 360 panoramas etc. in addition to static visualizations. On the other hand, complex semantic databases store information which helps to gain flexibility in planning gameplay, a form of virtual walkthrough or simulations related to the construction of investments (Fig. 5).

In most cases, the most relevant aspect is the entire created geometry of the scene, such as walls or building windows. Usually, when exporting the project to another program for visualisation, the data stored in the 3D models is lost, but this is not an obstacle when creating realistic representations of scenes and the data is not intended to be used in any other way. Scenes designed in BIM technology, e.g. on the basis of an imported geodetic map, are characterised by a very high level of accuracy in relation to real values, which is often difficult to achieve when modelling without references using traditional techniques.

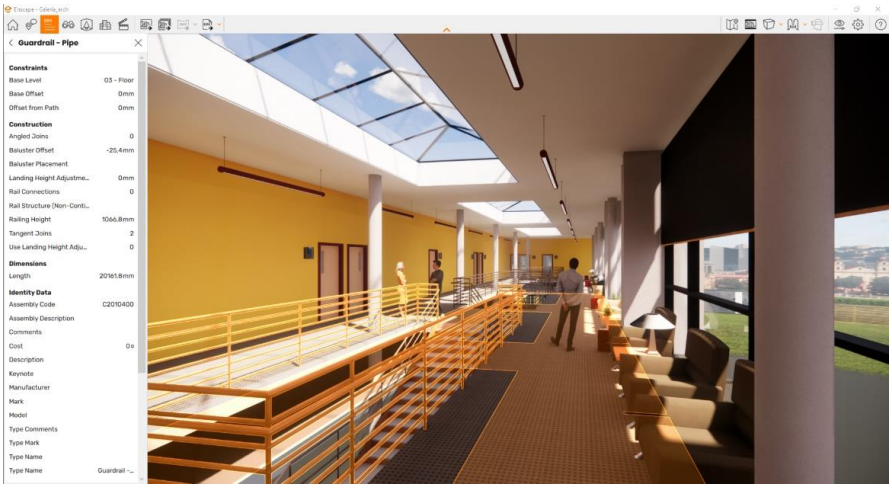

Fig. 5. Showcase of parameters stored in BIM model inside the Enscape engine. *Source:* own elaboration.

5. Integration of rendering engines into BIM programs

The process of creating visualisations of projects on the basis of BIM data is most often based on a plug-in created by the manufacturer, which allows to work directly in the program in which the scenes are created or to export data to an external editor - maintaining the connection between them (any change e.g. in Autodesk Revit is continuously transferred and visible in the second window) or not (the case of lack of automatic changes after exporting the geometry and other information) (Tab. 3).

Table 3. Types of integration of individual rendering engines into Autodesk Revit. *Source:* Own elaboration.

BIM software	Rendering engine	Type of integration
Autodesk Revit	Enscape	In program editing in real-time
	Unreal Engine	External editing in a dedicated program without preview of changes in project – necessary re-import of overwritten file
	Lumion	In program editing in real-time
	Twinmotion	External editing in a dedicated program without preview of changes in project – necessary re-import of overwritten file
	V-Ray	In program editing without real-time preview

While the presentation of the scene geometry in each engine is virtually identical, the default issue of the presentation of vegetation created in the project differs greatly depending on the selected software. For example, after importing to Unreal Engine, trees are not replaced by similar models from the existing library, but a simple object that was added in model mode is displayed.

The situation is different in the case of V-Ray or Enscape, where with different effects, but immediately trees are replaced by photorealistic internal library objects.

The basic path for creating grass in Revit is to create a plane representing the terrain and apply a two-dimensional texture to it. As in the example cited earlier - each manufacturer has provided a different way to visualise it:

- there is an advanced material editor built into the V-Ray engine that allows you to create it with specific parameters (Fig. 6),
- using Enscape, 3D grass is presented by default when the material assigned to the model has the "grass" attribute assigned in the appropriate window,
- in Unreal Engine, the plane itself is imported and the grass model and its distribution in the scene are created individually.

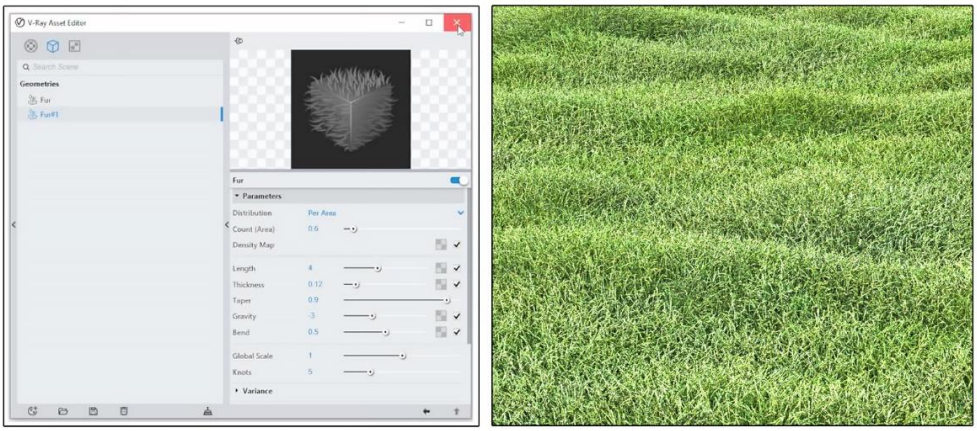

Fig. 6. Creation of grass material in the V-Ray rendering engine. *Source:* own elaboration.

6. Rendering in visualisation

In engines such as Unreal Engine or Enscape, what is presented in the internal editor is also the final result, so it is possible to quickly change and re-arrange elements at any stage of its creation. Due to the fact that the development of this technique is largely associated with computer games, many programs that use it allow the user to create, for example, virtual walks, enhancing the immersion of the presentation of projects. Several years ago, the only choice for creating photorealistic images (especially for high-budget films and visualisations of urban or architectural projects) were rendering engines like V-Ray representing an offline rendering approach [15]. This fact was caused, among others, by the hardware limitations of the time, but with the passage of time and the progressive development of technology, the qualitative boundary visible between the two methods is increasingly blurring (Fig. 7). With the announcement of new ray tracing APIs and supporting hardware, developers can easily create real-time applications with ray tracing as a core component (e.g. Twinmotion). As ray tracing on GPUs becomes faster, it will play an increasingly crucial role in real-time rendering. The dynamic development and competition of both approaches (offline and real time) only works to the advantage of the AEC industry [16].

Fig. 7. Example of visualisation using different rendering techniques – Offline (V-Ray) and Real-Time (Enscape). *Source:* own elaboration.

The basis for the development of rendering engines and the modelling and visualisation applications based on them is education. Education at universities not only of design, but also of the tools, will increase the competence of students and later designers in the job market. Practitioners, in turn, will set the direction of software development by reporting further needs. In education, elements of gamification can be implemented, which show greater effectiveness than the traditional approach [17]. The use of modern 3D or virtual reality (VR) technologies in teaching only strengthens the education process for students, who in turn feed the labour market [18].

7. Conclusion and discussion

The results of the work show that real-time rendering engines are becoming increasingly popular. The market will move towards dynamic scenes and animations, which customers are increasingly demanding in their projects. The advantages of real-time rendering engines are the speed of editing and the ability to observe changes synchronously. The development of real-time rendering engines has changed the balance of power in the market and is increasingly replacing existing offline rendering solutions. Manufacturers are either defending themselves against the changes or buying up competitors, as was the case with Enscape, which was acquired by the Chaos Group. Users thus have a wider choice of visualisation software and the increasing competition in the market is driving the development of applications. Applications increasingly offer the possibility to export to AR, VR or MR. Visualisation software is not the cheapest, but design studios are aware that its purchase is necessary. The popularity of real-time rendering engines is growing, with successive versions bringing new functionalities (e.g. path tracer in Twinmotion). The price range of the aforementioned applications is very wide, which certainly allows designers from different industries to choose. Regardless of the solution chosen, the end result is always the sum of the user's knowledge and skills.

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