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Comparative evaluation of model checking and clash detection software and its potential in Building Information Modeling

Ocena porównawcza oprogramowania do sprawdzania modeli i wykrywania kolizji oraz jego potencjału w modelowaniu informacji o budynku

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Abstract. The article presents the original results of empirical research focused on application of Building Information Modeling (BIM) in the Architecture, Engineering and Construction (AEC) practices, specifically on detection of clashes in a BIM model. This research is part of the project founded by the European Union. The study presents methodology, experimental phase and findings. The tests were conducted in five clash detection programs. A comparison of the results in terms of the quality of the feedback, and an assessment of its usefulness contributes with new knowledge that enhances sustainability aspects of BIM.

Keywords: Clash Detection; BIM; Building Information Modeling; BIM Model Analysis; Construction Ecosystem.

Streszczenie. W artykule przedstawiono oryginalne wyniki badań empirycznych ukierunkowanych na zastosowanie modelowania informacji o budynku (ang. *Building Information Modeling*, BIM) w sektorze architektury oraz inżynierii i budownictwa (ang. *Architecture, Engineering and Construction*, AEC), a przede wszystkim na wykrywanie kolizji w modelu BIM. Badania te są częścią projektu finansowanego przez Unię Europejską. W pracy przedstawiono metodę badań, fazę eksperymentalną oraz wyniki. Testy przeprowadzono w pięciu programach do wykrywania kolizji. Porównanie wyników pod względem jakości informacji zwrotnej i ocena jej przydatności wnoszą nową wiedzę, która przyczynia się do zrównoważonego rozwoju budownictwa dzięki stosowaniu BIM.

Słowa kluczowe: wykrywanie kolizji; BIM; modelowanie informacji o budynku; analizy modelu BIM; ekosystem budowlany.

Building Information Modeling (BIM) is becoming an integral part of construction processes and is being used increasingly in practice [1]. BIM is seen as a core technology that enables the creation of digital twins, or digitized replicas of the physical objects, processes and systems associated with a building [2]. BIM includes workflows and technology for digital, object-oriented modeling of building products and processes [3]. It is being increasingly used for advanced and diverse tasks in the AEC (Architecture, Engineering and Construction) sector [4, 5]. One of the problems occurring in construction processes that can be solved by BIM tools is making the collision of designed elements visible during construction. BIM can be used to detect these collisions as early as the virtual model creation stage (clash detection). The ability to avoid costly and labor-intensive error correction directly on the construction site is associated with benefits such as increased productivity, the ability to create teams from less skilled workers, less information exchanged, fewer changes to work schedules on site, and increased safety [6]. Consequently, clash detection has a major impact on construction efficiency and thus on the sustainability of the construction sector. Considering sustainability as the parallel satisfaction of social, economic, and environmental needs, the greater efficiency of operations achieved on the construction site ensures better use of human resources directly involved in the construction of a building. At the same time, this contributes to a good financial result for the company and the ability to better compensate personnel. Shorter time of construction reduces the impact of related inconveniences (such as noise, dirt, occupied infrastructure) on the surrounding area. Fewer errors also reduce the need for construction materials and the energy associated with their production and corrections on site, which, in addition to reducing costs, reduces the negative impact of construction on the climate.

When creating design documentation, designers must follow the rigid rules imposed by the construction law. The law and construction standards provide a fairly clear benchmark that serves to standardize the documentation produced. For this reason, design software has similar functionality, and any differences in the available BIM software are a matter of

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competitive advantage. Collision control is completely different, as it is not subject to standardization, and the differences in results for different programs are significant, as shown in the article.

Many users of collision detection systems note that many errors found by dedicated software are irrelevant to the structural correctness of the building [7, 8]. For this reason, automatic clash detection in software requires user verification, which includes reviewing the three-dimensional model from different angles and cross-sections, and then deciding if an error has been found that requires spending time to eliminate, or just a clash due to an incorrect interpretation of the software [9].

Manual verification of the intersections found is necessary but can also be very time-consuming [10]. Among the ways to reduce errors are the involvement of more accurate anti-collision software, but also coordinating the project interdisciplinary as early as possible and working in a common data environment [11].

The main purpose of this article is to present original empirical results focusing on clash detection in a BIM model using dedicated software. The BIM model was performed at Level of Detail (LOD) 350 [12]. LOD 350 was introduced by BIMForum because of the refinement of model detail classification guidelines by the AIA (American Institute of Architects). In LOD 350, each part of the model is a specific element, system or assembly with their size, shape, location, orientation, and interaction with other building systems. It is also possible to combine non-graphical data with a model element.

Selection of collision detection software for comprehensive testing

The study compared the functionality and user experience of several programs dedicated to collision detection. It allowed to check what possibilities this technology offers to designers. It should be noted that the market potential of collision detection in BIM is directly related to the inclusion of such software in academic programs.

It should be noted that apart from reviews of available programs on several websites, no studies comparing collision detection results were found. In addition to comparing the principle of the programs, suitable scenarios were sought to introduce them in an academic course. In this way, the ease of mastering the basic principles of the program and the availability of educational licenses were also evaluated.

After reviewing and pre-selecting, the analyzed programs, those that are extensions to commercial BIM programs (e.g., Revit) and based on point cloud instead of BIM formats were rejected. As a result of the selection, the test was conducted in five standalone collision detection programs: Solibri Model Checker (version 9.12.9.15); BIMvision (version 2.25.3); Trimble Connect (version 1.15.0.376); Open BIM Model Checker (version 2023.g) and usBIM.clash (version 8.00b). The software was installed on the same computer running Windows 10 version 21H2, and the tests were conducted without loading the hardware with other relevant processes to guarantee the same experimental conditions. The programs tested are used to automatically check a building model made with BIM technology using input data based on the Industry Foundation Classes (IFC) file format. IFC is a standardized text format that supports the export of BIM models by design software. Files in this format streamline the exchange of information between architectural, engineering and construction companies.

Collision detection programs vary in functionality, but what they have in common is checking whether the geometry of different building elements intersect with each other. Such collisions are known as "Hard Clash". In addition to this type of collision, there is also a type of "Soft Clash", which is the intersection of geometric spaces around objects or insufficient distance of an object in relation to other elements. Such spaces can symbolize, for example, required maintenance space around equipment or needed expansion joints between elements. Of the programs examined, only Solibri Model Checker can find "Soft Clash." There is also 4D Workflow Clash in the literature, i.e. collisions affecting work schedules [13], but none of the programs tested had this functionality. The programs can also visualize loaded IFC models and create graphical presentations based on the results.

The first of the programs tested was Solibri Model Checker [14]. In the free version (Solibri Anywhere), it can serve as a viewer of IFC files with the ability to create comments. The paid version (Solibri Office) extends the functionality by checking models according to rules built into the program or also additionally defined by the user. In addition, it is possible to create various types of model presentations and numerical data summaries in the program. There is no widely available educational version of the software, although it can be obtained by contacting local distributors.

The second program tested was BIMvision [15], which in its basic functionality is a free viewer of IFC models, but its basic functionality can be extended with paid plug-ins that include reporting, performing preliminary calculations or collision investigation, among others. For collision detection, the Clash Detection module can be purchased. An educational license for the full suite of plug-ins is available by submitting an inquiry to the software developer.

The third program tested was Trimble Connect [16], which is based on a cloud and available both online and as a computer application. The free version allows the user to create only one project, but the user also gets access to the program's full functionality. Thus, he can use the collision detection module. One model is sufficient for basic work and for learning the program. A characteristic feature of this tool is that it performs collision checking only between different IFC files occurring within a single project, for example, covering architectural and sanitary engineering separately. It is not possible to detect collisions of elements contained in a single file.

The fourth program tested was Open BIM Model Checker [17], linked to BIMserver.center. It requires creating an account on the aforementioned site, and then uploading the model to the server using IFC Uploader. The software is free, but as the manufacturer states on its website, the exception is a module for automatic collision detection, which requires written permission. The full version of the program, however, can be purchased from the manufacturer's website. If the project is marked on the server as created for educational purposes, the program allows the user to perform collision checks.

The last program tested was usBIM.clash [18]. This is paid software, available both online and for PCs. An educational version is available, which is obtained by filling out the appropriate form.

Test execution environment

To compare the programs, it was decided to run the collision checking procedures in each of them, in default mode and initial settings. The exception was Solibri Model Checker, in which different part checking procedures can be selected depending on the required scope and degree of verification. To ensure comparability of results, a procedure analogous to other software's scenarios was selected – Intersections Between Architectural Components, which verifies intersections of elements such as walls, windows, beams, etc.

First, the OTC Conference Center building design, provided by Autodesk Inc [19], was selected as the IFC model to be tested. It was decided to choose this model as an example of a comprehensive BIM model, equipped with both an architectural model and sanitary installations (Figures 1 and 2). The model contained 10,525 elements divided into 18 element types and 21,478 relationships.

After running the first tests of the said model in Solibri and Open BIM Model Checker, it turned out that 305 and 390 errors were found, respectively. The number of collisions was much higher than expected. When learning the program from the proposed scheme, it would have caused too much confusion for the potential user. In addition, what took about 30 seconds in Solibri, took 32 minutes in the second program tested. For these reasons, it was decided to change the building model to a simpler one. The model chosen was a single-family, one-story house with a usable attic (Figure 3), which contained 305 elements divided into 13 element types and 859 relationships. The smaller number of element types compared to the previous model was due to the fact that the model did not contain plumbing elements. Most programs treat each building element equally, converting it to geometry. The absence of these elements did not affect the evaluation of the program itself, while simplifying the work. After changing the model, the tests were repeated, running them again using the same IFC file in all the programs mentioned.

Empirical studies

The building model was first loaded into Solibri Model Checker and is displayed in the program in a 3D preview. There are several methods of displaying the model tree: by layer; component or floor division. The user can easily control the visibility of components by creating any combination using visibility tags. In addition, the user can display 2D drawing elements – axes and floor plans. The ease of navigation in the 3D preview and the large number of available options allow the user to efficiently perform the

Photo 1. The various elements in the tested conference center model (walls and ceilings were hidden)
Fot. 1. Różne elementy testowanego modelu centrum konferencyjnego (ściany i stropy zostały ukryte)

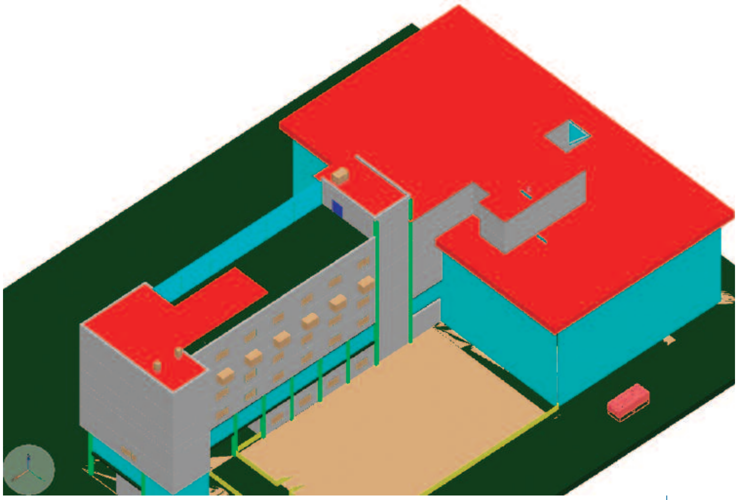


Photo 2. Tested conference center model
Fot. 2. Testowany model centrum konferencyjnego

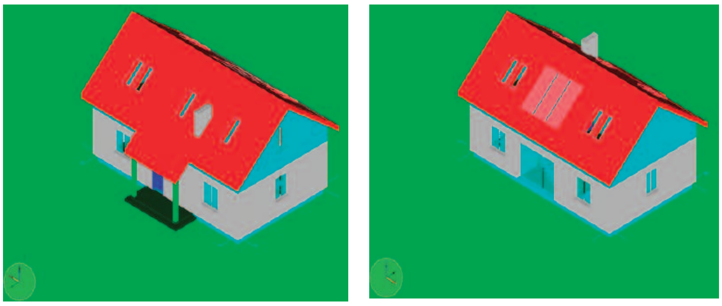


Photo 3. Isometric view of the tested model
Fot. 3. Widok aksonometryczny testowanego modelu

first stage of collision checking, i.e. visual inspection for intersections of geometry visible immediately, such as within floors. It has been observed that visual inspection is the most frequently used function by many Solibri users [20]. As already mentioned, Solibri Model Checker has an extensive checking module that covers many of the most common scenarios. They not only provide verification of geometric collisions, but also define geometry rules, such as the required free space in front of a window. Predefined rules can be edited, or the user can create his own rules.

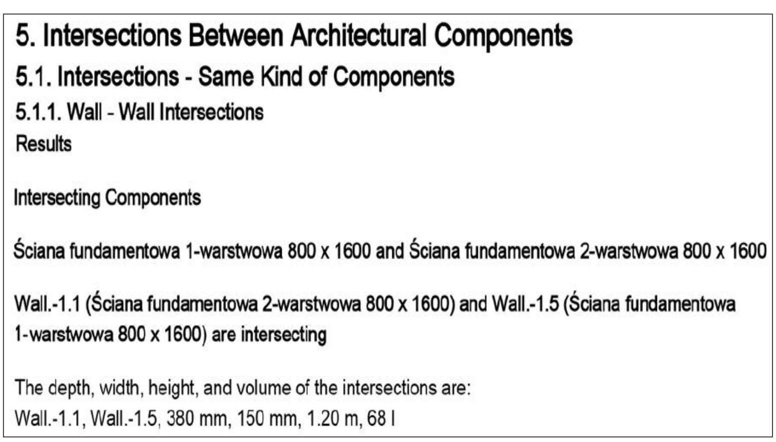
Detected clashes are divided into three groups according to the importance of the clash. Viewing the inspection results is intuitive, and it is easy to verify which elements of the building passed the inspection successfully, and where the program found potential errors. At this stage, the user can already sort collisions as irrelevant, i.e. acceptable, and resolved, or significant, i.e. eligible for inclusion in the report. Significant collisions can be presented in the form of a slide containing a description and illustration of the resulting collision. The slides can be published as a report, e.g. in PDF format (Figure 4, Table 1)).

The second set of empirical tests was conducted in BIMvision software. Viewing the model in BIMvision is also intuitive and has a large range of subdivisions for structure, types, groups, layers. An interesting feature is the ability to expand floors, which gives a full view of the building interior without hiding elements. A useful feature is the ability to measure objects with a click, making it easier to know, for example, the area, volume, or weight of an element. The user can also compare two models and clearly see what changes have been made. As for collision checking, other than setting the minimum volume of the intersection of two geometries that is considered a collision, there is no method for editing search results. The errors found are displayed as a single list, indicating the types of IFCs that collide with each other and the volume of the collision (Figure 5). The results can be supplied with comments, exported to a gallery or Excel file.

The Trimble Connect program, as already mentioned, is designed to test collisions between different IFC files. In the case of checking an architectural model, this would require exporting elements such as walls, floors, furniture into separate IFC files and then loading them into the program. From a practical point of view, this is quite complicated even though there is an option to enable "Ignore collisions in terms of the same type." In testing, an attempt was made to load two of the same IFC models. Collisions then indicated all intersections of analogous elements from both models. A check was then performed with the option to ignore collisions of the same type enabled. The number of collisions was much lower, but in addition to irrelevant collisions of two analogous walls, collisions of, for example, foundation walls that actually mattered were excluded. It was noted that the downside of checking collisions in this program is that all layers of a wall are treated as separate elements. Collisions in a wall are therefore detected, for example, by both the plaster and insulation layer and the structure.

Table 1. Summary check report from Solibri
Tabela 1. Raport podsumowujący z Solibri

Intersections Between Architectural Components	Accepted	Rejected	Major	Normal	Minor	Comment
Intersections - Same Kind of Components				x		
Wall - Wall Intersections				x		
Slab - Slab Intersections	OK					
Roof - Roof Intersections	OK					
Beam - Beam Intersections	OK					
Column - Column Intersections	OK					
Door - Door Intersections	OK					
Window - Window Intersections	OK					
Stair - Stair Intersections	OK					
Suspended Ceiling - Suspended Ceiling	-					
Railing - Railing Intersections	OK					
Ramp - Ramp Intersections	-					
Intersections - Different Kind of Components			x	x		
Door Intersections	OK					
Window Intersections	OK					
Column Intersections			x	x		
Beam Intersections			x	x		
Stair Intersections	OK					
Railing Intersections	OK					
Suspended Ceiling Intersections	OK					
Wall Intersections			x	x		
Slab Intersections	OK					
Roof Intersections	OK					
Intersections of Furniture and Other Objects				x		
Object Intersections	OK					
Doors/Windows and Objects	OK					
Objects and Other Components				x		


5. Intersections Between Architectural Components
5.1. Intersections - Same Kind of Components
5.1.1. Wall - Wall Intersections
Results

Intersecting Components

Ściana fundamentowa 1-warstwowa 800 x 1600 and Ściana fundamentowa 2-warstwowa 800 x 1600

Wall.-1.1 (Ściana fundamentowa 2-warstwowa 800 x 1600) and Wall.-1.5 (Ściana fundamentowa 1-warstwowa 800 x 1600) are intersecting

The depth, width, height, and volume of the intersections are:
Wall.-1.1, Wall.-1.5, 380 mm, 150 mm, 1.20 m, 68 l

Photo 4. View of a collision in a PDF report from Solibri
Fot. 4. Widok PDF z raportem kolizji z Solibri

The next program tested was Open BIM Model Checker. Working in this program requires uploading a file to a central BIMserver using IFC Uploader. The multi-step process is a non-intuitive impediment to using the tool. Once the program is loaded, the user can manually add items and select model categories to be included in the collision checking tool. Once the collision checker is finished, collisions can be displayed in a clear way and notifications can be created.

The last program tested was usBIM.clash. It first requires the model to be loaded. The results obtained allow the user to comment, accept and

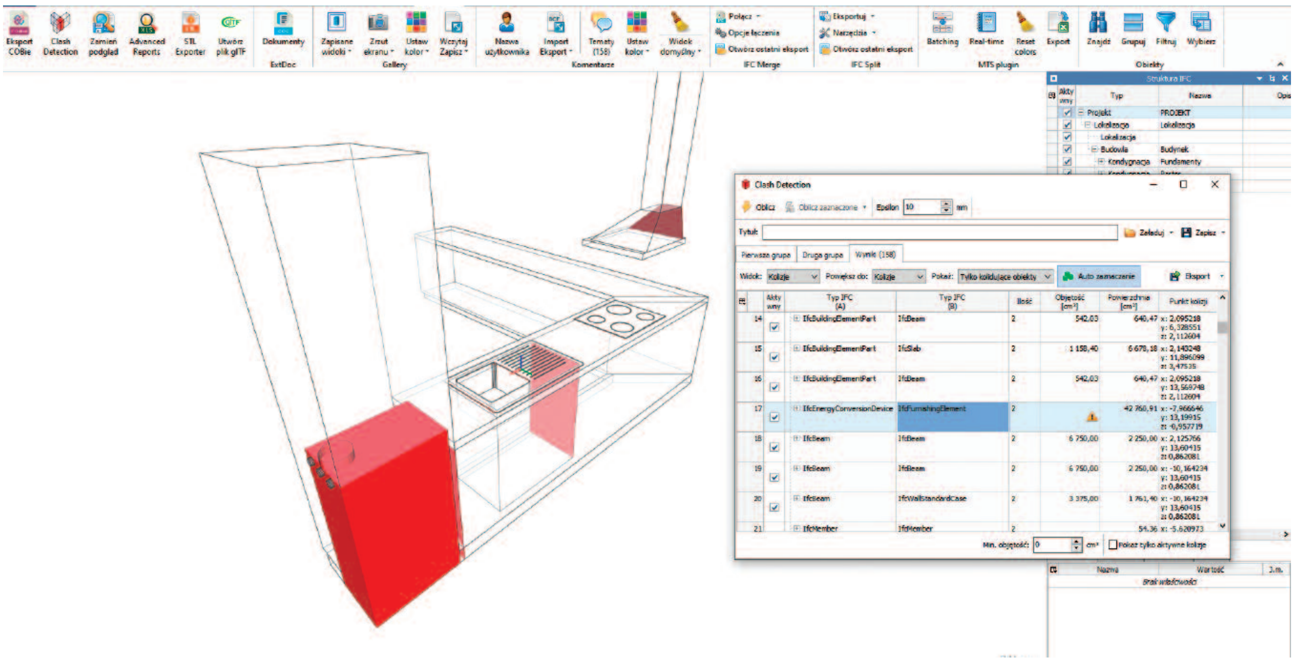


Photo 5. Presentation of collision in BIMvision
Fot. 5. Prezentacja kolizji w BIMvision

export reports. The program considers collisions of elements that were clipped in the source program. In addition, collisions such as a wall standing on a ceiling or a rung in a railing intersecting with a handrail appear.

Discussion of the results and conclusions

As mentioned earlier, the main principle of the empirical study was to select programs that are free for users to use within academic programs. What's more, the collision detection procedure was run based on the same IFC model of a single-family house, which made it possible to obtain comparable results. The quality of the feedback provided by the program, the form of its presentation and the evaluation of its usefulness from the user's point of view were the main research issues that were observed and analyzed. In this connection, the most common mistakes were also discussed. The results showed a large scale of differences between programs, reaching several hundred percent in terms of the number of collisions detected (Table 2). A higher number of them did not always equate to more useful feedback, as some of the collisions were due to incorrect visualization of the IFC model and resulted in incorrect geometric interpretation of the collision.

Table 2. A number of detected collisions
Tabela 2. Liczba wykrytych kolizji

Program	Number of collisions detected
Solibri Model Checker*	22
BIMvision**	158
Trimble Connect***	69
Open BIM Model Checker	40
usBIM.clash	179

* for the "Intersection Between Architectural Components" mode;
** together with the "Clash Detection" plugin;
*** with the 'Ignore clashes within the same type' option enabled

Considering the potential of collision detection tools, the first conclusion of the experimental study is that Solibri has the greatest ability to set different options for model analysis. On the one hand, like other programs, it can be used to check the integrity and quality of a building model, and on the other hand to verify the content of the model with respect to, for example: building regulations or ergonomic requirements. At the same time, however, this is a barrier for novice users of the program. Other than a thirty-day trial period, there is no open educational license.

The BIMvision program showed many collisions that were not errors, such as the intersection of two walls. Reviewing collisions and reporting topics in the program is very easy. Handling many submissions is therefore efficient. A one-time educational license, however, puts a barrier in front of the learner, as subsequent licenses are only available through an agreement between the university and the product provider. Trimble Connect's inability to work on a single file is a major obstacle that disqualifies the program from the start.

Open BIM Model Checker shows the number of collisions that can support the designer. In addition, the program is easy to use. However, I found some of the collisions indicated to be problematic, such as the collision of a window opening with a window within that opening. Navigation in the model view window is somewhat problematic. In usBIM.clash, as in BIMvision, many geometric intersections are considered. From the perspective of the tests carried out, Solibri showed the lowest number of unsubstantiated collisions, although the intersection of two correct footings, for example, was indicated. A full comparison of the collision detection tools is shown in Table 3.

Table 3. Comparison of selected clash detection tools
Tabela 3. Porównanie wybranych narzędzi wykrywania kolizji

Program/ Feature	Solibri Model Checker	BIMvision	Trimble Connect	Open BIM Model Checker	usBIM. clash
Availability of the educational version	no	yes/3 months	yes/full functionality available for 1 model	yes/ the model must be descri-bed as 'educational'	yes
Time--limited trial version	yes	yes/demo versions of plug-ins	yes	nie	yes
IFC viewer with custo-misable range of presented elements	yes	yes	yes	yes	yes
Collision detection with custo-misable range	yes	no	no	no	no
Marking of collisions found	yes	yes	yes	yes	yes
Creating a report in PDF format	yes	yes	no	yes/without 3D previews	yes

The results of the study indicate that collision checking tools can provide valuable assistance in coordinating design work and inter-industry exchange. However, it is vitally important that the work of monitoring potential collisions is carried out with a person with experience and knowledge of construction. Coordination skills and knowledge of project management are not enough, as the results of inspections must be backed up by manual, factual verification in every case. For the potential user, as important as the ability to use the program is the ability to assess the usefulness of the feedback received. Users should therefore be encouraged to critically evaluate the results obtained.

There are many studies that confirm that the degree of application of BIM technology in AEC practice is still unsatisfactory, not only in Poland [21], but also globally [22]. Thus, the results of the presented research may prove useful in the process of implementing BIM in construction companies.

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