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ARCHITECTURAL DESIGN QUALITY BETWEEN BIM COLLABORATIVE LOGIC AND TRADITIONAL CAD LOGIC

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ABSTRACT

Building Information Modeling, often referred to as BIM, is considered an essential part of the design and construction process in many countries. The aim of this study is to test the application of this system in relation to traditional computer aide design (CAD) and to characterize the possible contribution of BIM to architectural quality. The analysis model consists of modeling the design process through an exercise proposed to student architects. The proposed solutions were subjected to a detailed statistical analysis in order to characterize the contribution of BIM elements to design quality. The results show that out of five evaluation criteria, four are in favor of BIM, with a percentage of 80%. For the functionality criteria, the results of the BIM approach and those of CAD are reconciled for the remaining 20%. This research confirms that architectural design using BIM tools, even with a low level of collaboration, leads to a higher quality design than the traditional CAD-based approach.

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1. INTRODUCTION.

The Algerian construction industry suffers from a number of shortcomings, including delays in project execution and poor-quality workmanship. It is becoming increasingly important to find a way of overcoming these shortcomings by adopting new approaches and technologies. (Bouguerra et al., 2020)

Since the advent of IT tools, architects and construction professionals have been using them to improve their performance. (Guéneau, 2019) Traditional methods used in the design process have evolved from 2D Computer Aided Design (CAD) to Building Information Modeling (BIM). (Heffernan et al., 2017).

The quality of architectural design also depends on the quality of communication between the various parties involved in the project, such as architects, engineers, contractors and users. Clear and open communication is essential to ensure a coherent and harmonious design that meets the needs and expectations of all stakeholders. (Calixte et al., 2022).

The advent of the BIM paradigm has turned practices on their head, bringing plus in terms of collaboration and improved coordination between the various project stakeholders through the digital mock-up and the ease of file exchange. (Heffernan et al., 2017).

The aim of this research is to characterize the role of the BIM system in the design of quality architecture in relation to traditional CAD-CAM drawing systems and to show the possible difference between traditional CAD-based design and the collaborative logic of BIM (building information modeling).

2. STATE OF THE ART.

BIM technology is a revolutionary development that is rapidly reshaping the AEC industry and changing the way we build. (Ziwen & Yujie, 2019).

Recent years have seen the rapid development of digital representations of buildings known as BIM (building information modeling). The concept stems from a need for improved collaboration and information exchange (Andriamamonjy et al., 2019), it acts as a collaboration and centralized database between stakeholders. (Heffernan et al., 2017)

The study conducted by Andriamamonjy (Andriamamonjy et al., 2019) identified six main research themes related to BIM. These are the adoption of BIM adoption (Miettinen & Paavola, 2014), life cycle assessment (Basbagill et al., 2013) progress monitoring (Kim et al., 2013), interoperability (Sacks et al., 2010), energy simulation (Welle et al., 2011) and process-assisted management. He indicates that these are some of the most important areas of research currently being carried out in the field. On the other hand, when it comes to the integration of energy simulation and BIM, fewer researchers are interested in this subject than the other groups.

While BIM awareness is high in most developed countries (US, UK, France, Finland, Korea and others), this study will focus on BIM focus and implementation in developing countries. Although it identified the key factors that can influence the success of this technology in this region, it also noted that there is a lack of research into the multiple factors that can influence the success of this process in this region. To fill this gap, the researchers used a structural equation modeling approach to analyze the data. (Tan et al., 2022)

According to the study, various factors such as government support (Saka & Chan, 2020), education (Babatunde et al., 2018), (Awwad et al., 2022) and training (Liu et al., 2022) are crucial for the implementation of BIM in developing countries.

Another academic study examines the literature on the role of BIM in sustainable construction from a perspective not covered by existing studies. Instead of focusing on the application of BIM in the different phases of the project. The authors were able to successfully answer the research question by conducting a computational analysis of the literature and classifying it based on a content analysis of 317 journal articles published between 2008 and 2017.

Currently. Regarding the terms most used by authors, "sustainability", "energy efficiency", "green building" and "safety" are among the first, in addition to those most used in BIM literature. (de Carvalho et al., 2017) In summary, the main challenges and gaps identified by the authors are: interoperability issues between BIM and sustainability tools and the lack of ontologies in sustainable construction domains; the lack of standards and public incentives for BIM adoption. (Santos et al., 2019)

In addition, research by (Pereira et al., 2021) presents a scientometric analysis of BIM, analyzing a large number of scientific articles in order to characterize the current state of research into the subject under study. The results of this research show that BIM can improve energy efficiency, and that one of the gaps is the level of information exchange, in other words, interoperability. Following this study, they were able to conclude that the "Revit©" modeling software is the most widely used, and as far as energy calculations are concerned, the most frequently cited software packages are: EnergyPlus©, Ecotect©, Green Building Studio© and IES©, while ArchiCAD©, the software most used by architects, is less interoperable despite the contribution of other energy calculation software such as Archiwizard©, which has a link with ArchiCAD© and Revit©.

BIM is not a standalone technology, but a technology-assisted collaborative process, with about 90% process and 10% technology. (Abdullahi & Chan, 2019). In Africa its adoption and implementation remain slow and lagging behind developed countries (Saka & Chan, 2019). In Algeria, research on BIM is in its infancy, as evidenced by the few publications in the field (only 03), which focus on issues that do not touch the heart of BIM (Bouguerra et al., 2020).

In Algeria, architectural production is characterized by the quest for quantity to the detriment of quality; building quickly has ended up producing a mediocre built environment. This is due to a number of factors affecting several levels: project management, contracting and construction. (Laroui, 2017) The latter is characterized by a lack of collaboration between project stakeholders (Chaabi, 2017) which results in a linear planning with no feedback and in which the use of specialized software is limited to drawing (Saighi & Zerouala, 2018).

3. MATERIALS AND METHODS.

The analysis model consists in modeling the design process in the field through an exercise proposed to the student architects. The exercise consists of the architectural design of a cafeteria project for teachers at the University of Oum El Bouaghi. The site is given in advance with the program and, above all, the requirement to design a project whose main space (the consumption space) must be naturally lit and free of obtrusive posts, these requirements to be used to characterize the role of collaboration in solving these problems. This first phase will be followed by a detailed statistical analysis of the process to characterize the contribution of BIM elements to design quality. The experimental model was built at the Architecture Department of the Faculty of Architecture of Larbi Ben Mhidi University in Oum El Bouaghi. During this experiment, different working approaches were confronted with the use of different CAD software, such as AUTOCAD© or ARCHICAD©, with or without the assistance of experts. The group working within the collaborative framework (BIM) is connected to the experts via the network: the location of the rooms was chosen according to the consultants' room, as these three rooms are connected by a network that allows us to apply the exchange between the actors (student, structural engineer and climate consultant). Distance is therefore an essential parameter in the operation of the network.

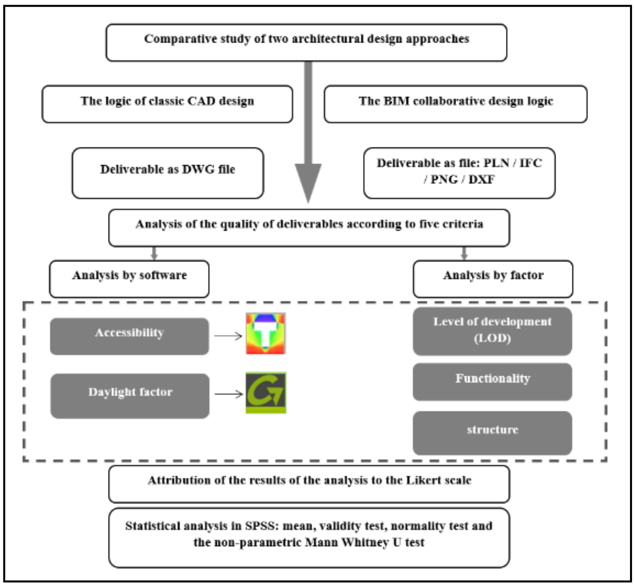

Figure 1. Explanatory diagram of the work process, source: authors (2023).

The analysis is based on a set of sub-criteria (five sub-criteria), as shown in the table, which were identified following a literature review and evaluated using dedicated software,

Table 1. Analysis quality criteria.

The criteria	References
Daylighting	(Harputlugil et al., 2014), (Suratkon & Jusoh, 2015), (Chen & Pan, 2015), (Giel & Issa, 2016), (Eryürük et al., 2022), (Das, 2022)
Accessibility	(Choi & Inhan, 2013), (Giel & Issa, 2016), (Eryürük et al., 2022), (Tian et al., 2022), (Das, 2022).
functionality	(Choi & Inhan, 2013), (Giel & Issa, 2016)
Structure	(Suratkon & Jusoh, 2015), (Chen & Pan, 2015), (Giel & Issa, 2016), (Das, 2022)
Lod (detail level)	(Harputlugil et al., 2014), (Giel & Issa, 2016), (Reeves et al., 2015)

4. SOFTWARE DEDICATED TO ANALYSIS.

4.1 The protocol for working with ARCHIWIZARD© software.

Archiwizard©, which specializes in building energy calculations, is a GRAITEC product and a software package that uses BIM technology, which is why it was chosen. (Ebrahimi et al., 2022)

When the participant decides to carry out an energy consultation, he sends his model in IFC format to the HVAC consultant who uses the same software. The model is stored on the collaborative platform and can be retrieved in IFC format or other formats such as PDF or JPEG.

For the group that worked with the BIM collaborative logic, the results of the FLJ (daylight factor) analysis were provided with the deliverable files at the end of the experiment by the participants or on the platform; whereas for the group that adopted the traditional CAD approach using AutoCAD© software, a series of FLJ simulations (30 in total) were carried out after the design phase to evaluate this parameter and thus characterize the difference between the two approaches.

The two figures (2.3) show the results of the FLJ analysis of the two groups as a whole. In the group that used the collaborative logic in ArchiCAD©, four participants consulted the expert twice, giving a total of two simulations per participant.

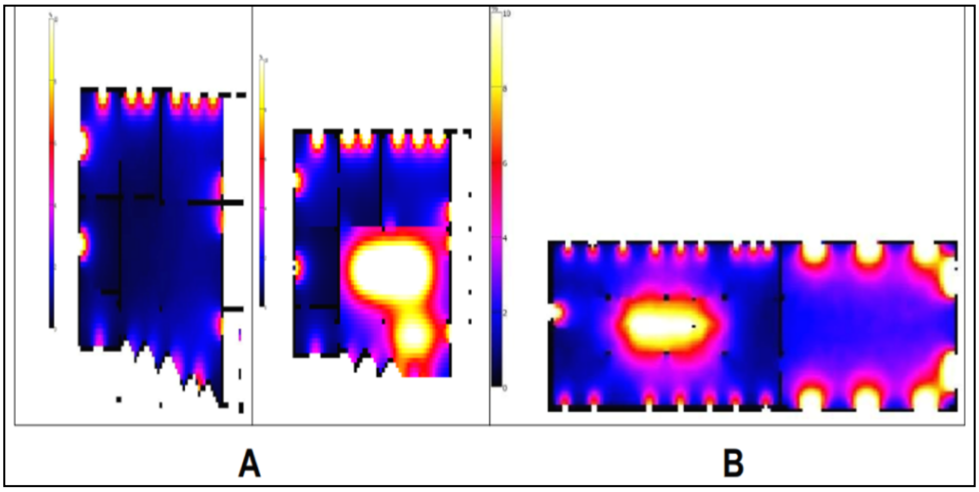

Figure 2. Some Results of the calculation of the daylight factor criteria in Archiwizard© for the ArchiCAD© group with climatic assistance.
Source: Authors.

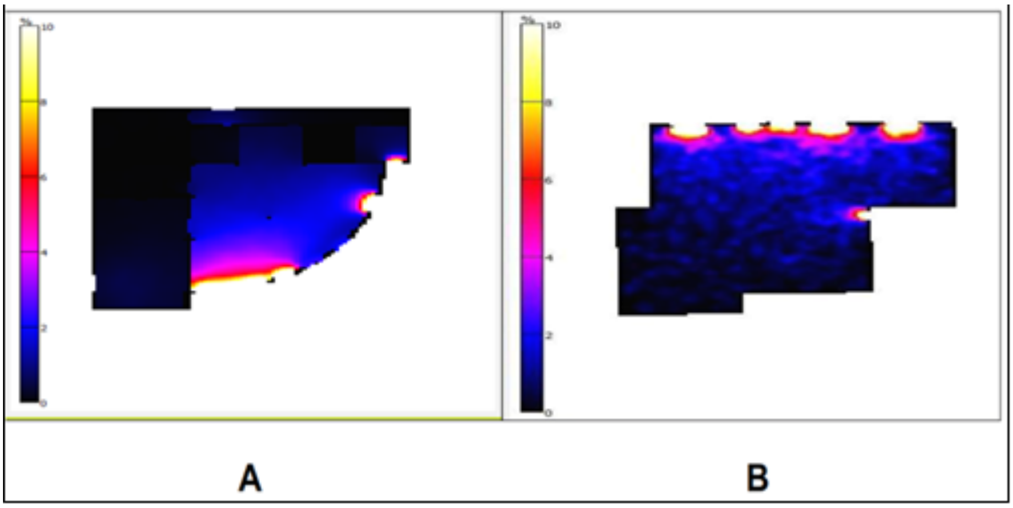

Figure 3. Some Results of the calculation of the daylight factor criteria in Archiwizard© for the autoCAD© group with climatic assistance.
Source: Authors (2022).

4.2 Syntax analysis with Depthmap.

The Depthmap software platform is used to perform spatial network analysis to understand social processes in the built environment. It can be used at different scales, from the building to the city. The software aims to map elements of open space using the topological relationships between them. (Turner et al., 2023)

4.3 The protocol for working with Depth map© software.

The axial map was chosen from the Depthmap© software tools in order to be able to assess the accessibility of the project in relation to the terrain for the two design approaches by identifying the main traffic routes serving the project.

This operation is carried out as follows:

- The insertion of the project given in the exercise into the existing master plan of the university campus, which includes the project's site.
- AutoCAD clean-up of the new ground plan with the inserted project, deleting all redundant elements not required for the axial simulation.
- Reduction of the "all line axial map" obtained to a "fewest line map" to make it easier to read (Hegazi et al., 2022).

The results of this analysis are shown in figures 5 and 6. The rating scale is based on the average of the values obtained from the axial lines, which reflect the degree of accessibility of the routes leading to the project.

The color scheme, ranging from dark blue (minimum value) to red (maximum value), reflects the different value scales. In terms of the overall reading, the shallowest axes are the most integrated and automatically the busiest; they are therefore the axes on which the student designer should focus his project. The deepest axes are the least frequented and also the most segregated. (Laouar et al., 2017).

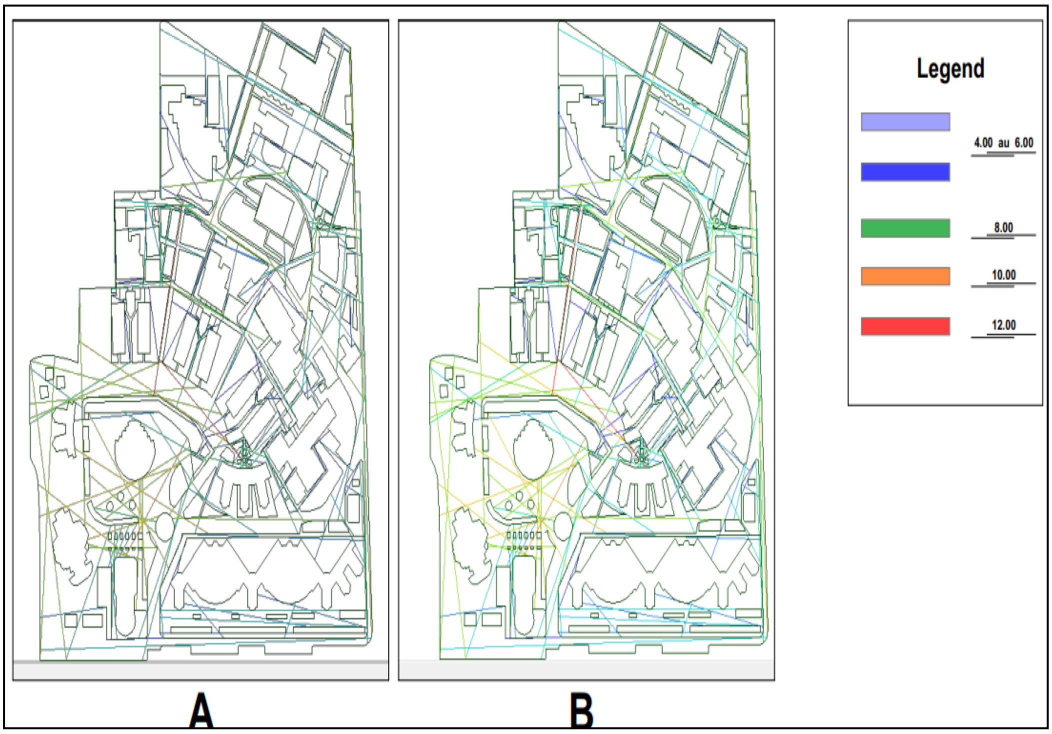

Figure 4. Some of the results of the axial map of the participants of the ArchiCAD© group.
Source: Authors (2023).

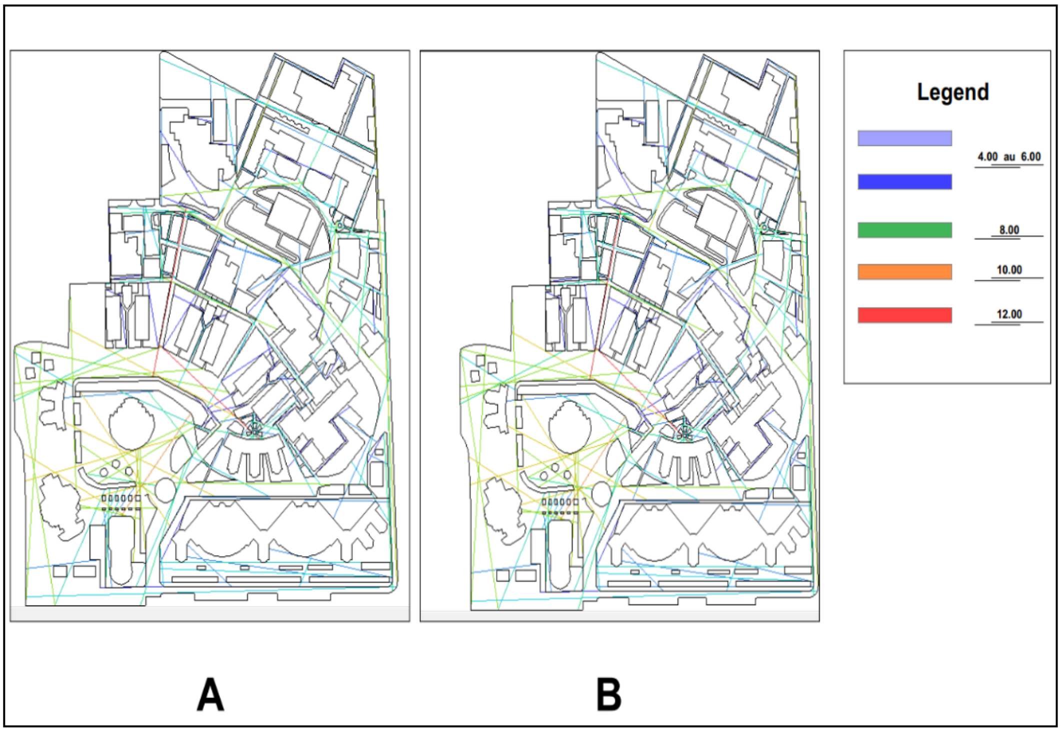

Figure 5. Some of the results of the axial map of the participants of the AutoCAD© group.
Source: Authors (2023).

Table 2. Summary of the methodology used to analyze the architectural quality criteria for the deliverable.

Criteria	Definition of criteria	The analysis method	Assessment using the Likert scale
1	2	3	4
Lighting	FLJ expresses the ratio between indoor illuminance at a point on the reference plane and horizontal outdoor illuminance on a clear site, under overcast conditions, known as CIE. It is expressed as a percentage	Simulation with Archiwizard© 2022 software (student license)	1: very low 2: low 3: average 4: good 5: excellent
Accessibility	of the building must be well resolved for different populations: pedestrians, disabled people.	Simulation using Depthmap© open source software	1: very low 2: low 3: average 4: good 5: excellent
Functionality	The way in which the building can be used for its various functions This is broken down into three terms: accessibility, space (dimensions and interrelationships) and uses (functions and future developments).	The presence of all the project spaces Respect for the area given in the exercise The relationship between the rooms	1: very low 2: low 3: average 4: good 5: excellent

Table 2. Continuation.

1	2	3	4
Structure	The framework is made up of load-bearing elements and its configuration is responsible for the stability of the structure.	Dimensions of structural members Joints between structural members	1: very low 2: low 3: average 4: good 5: excellent
Lod (detail level)	Refers to the geometric accuracy of a digital model, characterized by the precision of the 3D objects that make it up.	LOD 0 = two-dimensional rendering LOD 1 = perspective LOD 2 = perspective + breakthrough LOD 3 = perspective + breakthrough + search for a sustainable strategy (solar capture) LOD 4 = perspective + breakthrough + search for a sustainable strategy (solar capture) + architectural details	1: very low 2: low 3: average 4: good 5: excellent

5. RESULTS AND DISCUSSION.

The figure below shows the results of the Likert scale analysis of the five criteria for architectural quality.

Table 3. Summary table of the results of the Likert scale analysis: source authors (2022).

The design group using BIM logic																															
The criteria	**Lighting**	**5**	**5**	**5**	**2**	**2**	**3**	**5**	**5**	**4**	**4**	**5**	**2**	**3**	**3**	**3**	**5**	**2**	**2**	**5**	**5**	**1**	**1**	**5**	**2**	**5**	**2**	**5**	**5**	**3**	**5**
	Accessibility	**3**	**5**	**3**	**5**	**4**	**4**	**5**	**3**	**4**	**1**	**4**	**3**	**2**	**5**	**5**	**4**	**3**	**4**	**5**	**1**	**3**	**1**	**3**	**3**	**5**	**4**	**3**	**3**	**5**	**3**
	functionality	**4**	**5**	**4**	**5**	**5**	**4**	**4**	**4**	**4**	**4**	**5**	**5**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**5**	**4**	**4**	**4**
	Structure	**5**	**5**	**5**	**4**	**5**	**5**	**5**	**5**	**5**	**5**	**4**	**5**	**5**	**5**	**5**	**4**	**4**	**4**	**4**	**5**	**5**	**4**	**5**	**5**	**5**	**5**	**5**	**4**	**4**	**5**
	LOD (level of detail)	**4**	**5**	**4**	**5**	**5**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**5**	**4**	**4**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**4**	**5**	**4**	**4**	**4**
The design group using classic CAO logic																															
The criteria	**Lighting**	**1**	**2**	**2**	**1**	**4**	**2**	**1**	**3**	**2**	**3**	**4**	**3**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**3**	**1**	**2**	**3**	**1**	**3**	**4**
	Accessibility	**3**	**5**	**4**	**1**	**3**	**1**	**1**	**1**	**1**	**5**	**3**	**1**	**5**	**5**	**1**	**5**	**2**	**4**	**2**	**4**	**5**	**1**	**1**	**2**	**3**	**5**	**5**	**1**	**1**	**1**
	functionality	**4**	**4**	**4**	**4**	**4**	**3**	**4**	**4**	**3**	**3**	**5**	**3**	**4**	**4**	**4**	**4**	**5**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**2**	**4**	**4**
	Structure	**2**	**3**	**3**	**4**	**4**	**3**	**3**	**3**	**3**	**3**	**4**	**2**	**4**	**3**	**3**	**4**	**3**	**3**	**4**	**3**	**4**	**3**	**4**	**3**	**3**	**4**	**3**	**2**	**3**	**3**
	LOD (level of detail)	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

5.1 Statistical analysis using SPSS©.

In order to determine what comparison test could be used in this case study, a Kolmogorov-Smirnov normality test was carried out. Then the Cronbach's Alpha static validity test was used to assess reliability, which requires a score above 0.7. To see how the qualitative elements of the process differ, descriptive statistics are used to compare the means of two independent groups. The difference between the use of a BIM process and the use of CAD is explained on the basis of a number of qualitative elements. Finally, the results were compared between two independent groups using the Mann-Whitney U test. The normality test:

Regarding the Kolmogorov-Smirnov normality test, the data are not normally distributed, so we chose the Mann-Whitney U comparison test to characterize the difference between the two groups studied.

Tests of Normality

	Groupes	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistiques	ddl	Sig.	Statistiques	ddl	Sig.
Accessibilité_général_projet	groupe_archicad	,198	30	,004	,868	30	,002
	groupe_autocad	,246	30	,000	,797	30	,000

Tests of Normality

	Groupes	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistiques	ddl	Sig.	Statistiques	ddl	Sig.
FLJ_éclairement	groupe_archicad	,294	30	,000	,800	30	,000
	groupe_autocad	,280	30	,000	,802	30	,000

Tests of Normality

	Groupes	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistiques	ddl	Sig.	Statistiques	ddl	Sig.
Mise_place_structure	groupe_archicad	,440	30	,000	,577	30	,000
	groupe_autocad	,328	30	,000	,765	30	,000

Tests of Normality

	Groupes	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistiques	ddl	Sig.	Statistiques	ddl	Sig.
Qualité_rendu_3D	groupe_archicad	,473	30	,000	,526	30	,000
	groupe_autocad	.	30	.	.	30	.

Tests of Normality

	Groupes	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Fonctionnement	groupe_archicad	.488	30	.000	.492	30	.000
	groupe_autocad	.426	30	.000	.664	30	.000

a. Lilliefors Significance Correction

Figure 6. Normality test for the five criteria used to analyze architectural quality done by SPSS©
Source: Authors (2023).

5.2 Cronbach's alpha reliability test.

It measures internal consistency, or how well the items relate to each other. It is considered a measure of the reliability of the scale. For our analysis, this coefficient is approximately 0.975 this teste is a measure of internal consistency, the degree of relationship between a set of items as a group. It is considered a measure of the reliability of a scale. For our analysis, this coefficient is of the order of 0.975.

Table 4. Reliability statistics.

Cronbach's Alpha	Number of elements
0.795	5

5.3 Comparison of the average obtained for the two groups.

The level obtained is the result of a comparison of the mean value found with the mean value of the Likert scale, which is equal to three (3). All the criteria were highly rated for the group working with BIM logic compared to only one highly rated criterion for the traditional CAD group, with a 0.34 difference between them.

Table 5. Average value of the two groups with the level obtained source: authors 2023.

The criteria	Groups			
	BIM logic	level	CAD logic	Level
LOD (level of detail)	4.2333	High	1	Low
Accessibility	3.533	High	2.73	Medium
Functionality	4.20	High	3.8667	High
Structure	4.70	High	3.2	Medium
Daylight factor	3.6333	High	1.93	Low

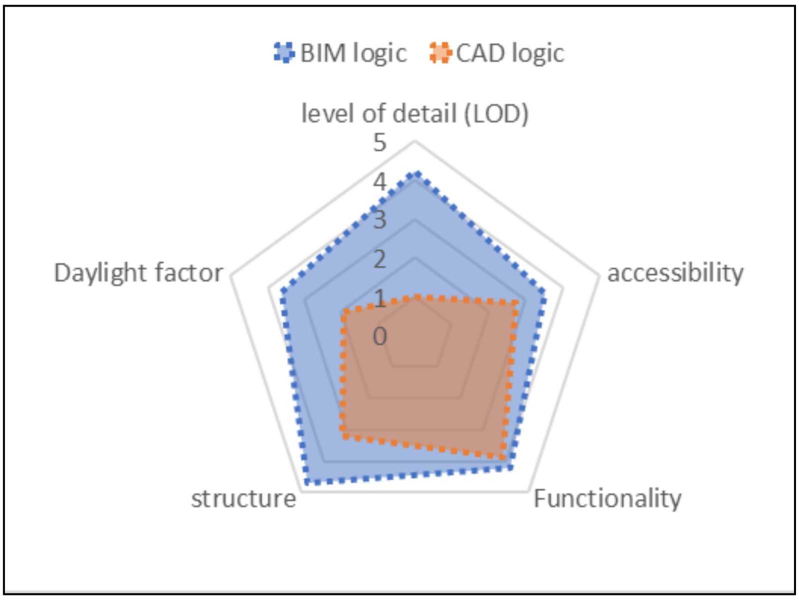

Figure 7. Radar diagram of the average obtained by the two architectural design approaches according to the five quality criteria.

The area covered by the average values of the five criteria for the group that worked with the logic of classical design is smaller than that of the second group that worked with the logic of collaborative BIM, which has a much larger area and where the average values of the criteria are almost all in the order of 4, while for the other group, it can be seen that only one criterion reaches this value (operation), while for the others, the values decrease and even reach a value of 1.

5.4 The non-parametric Mann Whitney U comparison test:

The results obtained make it possible to reject the null hypothesis and confirm that the distribution between the two groups is not identical, which explains why there is a difference between the two groups (the two design approaches). The results obtained by the BIM group have higher average ranks for the four criteria, except for the "operation" criterion, whose distribution is identical in the two groups, while the Kolmogorov-Smirnov test rejects the null hypothesis. These results confirm the results of the descriptive statistics of the means.

Table 5. P-value results of the non-parametric comparison test.

The criteria	Sig (U de Mann Witney)	Sig (Kolmogorov Smirnov)	Decision
LOD (level of detail)	0.000	/	Reject null hypothesis
Aaccessibility	0.068	0.035	Retain the null hypothesis
Functionality	0.014	0.799	Reject the null hypothesis
structure	0.000	0.000	Reject null hypothesis
Daylight factor (DFL)	0.000	0.003	Reject null hypothesis

6. CONCLUSION.

Architectural design is a complex process that requires a collaborative approach to problem solving. Incorporating the BIM process in the conceptual phase can reduce design shortcomings while ensuring the architectural quality of the product.

The participating students were confronted with a work process that was implemented for the first time in the Faculty of Architecture at Oum El Bouaghi University.

The result shows that collaborative design with BIM has produced a significant result in contrast to the logic of traditional CAD. Of all the criteria in the analysis, four tipped the balance in favor of the BIM process: the quality of the 3D, the layout of the structure, the daylight factor FLJ and "general accessibility" with a percentage of 80%. As for the last criterion (operation), the results of the two groups are similar, with a percentage of 20%.

Discussions with the consultants also confirm the important role played by the "structure and FLJ design" criterion in improving the results; any advice, whether structural or climatic, helps to reduce the error rate and helps the designer to make the optimum choice.

The analysis of the accessibility of the project, following the "space syntax" paradigm and using Depth map© software, can be integrated into the BIM process during future research, in parallel with the integration of the MEP player (plumbing, electrical, mechanical) to achieve a more advanced level of detail.

Declaration of Interest Statement.
The author declare that she has no conflict of interest.

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