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An overview of CFD simulation plug-ins within the BIM environment for urban microclimate analysis

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Abstract

Despite the vast array of building simulation tools available, there is a scarcity of microclimate-sensitive decision-support tools for urban planning early-stage design, where crucial decisions shaping microclimate and comfort conditions are made. Within the collaborative work environment of Building Information Modelling (BIM), researchers are innovating methods and software like Computational Fluid Dynamics (CFD) simulation tools to enhance and integrate outdoor environmental research in the design process. Incorporating CFD methods via plug-ins into architectural design software may represent a significant advancement in interoperability. However, the reliability, computational complexity, and accuracy of BIM-CFD integration remain unclear. To address the knowledge gap, this paper aims to conduct an in-depth study and comparison of the applicability of some CFD plug-ins for urban microclimate analysis in BIM projects. This systematic approach aims to build a comprehensive framework of BIM-CFD interoperability via plug-ins, identifying limitations and opportunities for integrating microclimate analysis into BIM design. Significant challenges are detected, particularly in data loss during model transfers and the limited scope of current CFD application methods. This review identifies the need for future research to explore multi-objective simulations and the integration of CFD feedback to optimise design, inform decision-making and optimise resources from the early design stages.

Keywords: Microclimate; Numerical simulation; CFD; BIM; Interoperability

1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC), fast-growing urbanisation worldwide has strongly increased the frequency and intensity of extreme weather events, by modifying the spatial distribution and intensity of human activity-related greenhouse gases (GHG) emissions (Core Writing Team et al., 2023a). Although urban development aims to contribute to the liveability and well-being of cities by providing citizens with physical, economic, and social benefits (Lai et al., 2019), contemporary urban design trends are conversely endangering both human comfort and urban microclimate conditions (Core Writing Team et al., 2023b). Urbanisation is causing severe urban overheating, which significantly affects individuals, infrastructure, the economy, and the overall urban environment. This issue demands urgent attention and the implementation of comprehensive solutions.

Despite the reported impacts of the built environment on human-driven climate change (Core

Writing Team et al., 2023b, 2023a; IEA, 2021), it also presents an opportunity to contribute to achieving sustainable development goals (SDGs) (Delval et al., 2021). The European Union (EU) has been formulating and implementing directives to enhance sustainability levels within the building sector (European Commission, 2012).

Technological advancements within the Architecture, Engineering, Construction, and Operation (AECO) industry are primarily centred around three key trends (Collao et al., 2021): (1) Prefabrication of construction elements, (2) Reduction of projects' carbon footprint, and (3) Digitalisation of projects (Collao et al., 2021). Project digitalisation has unlocked the potential for collaborative, integrated and information-based methodologies (Santos & Costa, 2017), driving the transition to more efficient sustainable development paradigms (Han et al., 2018). Facilitating collaboration and data exchange among the diverse stakeholders is essential to achieve design outcomes that address multiple objectives, encompassing not only the enhancement of urban microclimate and comfort conditions but also the reduction of GHG emissions and lifecycle costs (Han et al., 2018; Santos & Costa, 2017).

Building Information Modelling (BIM) has emerged as a fundamental work platform for digital transformation in design practices (Collao et al., 2021). BIM, as defined in (ISO 29481-1:2016, 2016), refers to a methodology that enables the modelling of a shared digital 3D representation of any constructed entity with physical and functional attributes. This information model displays as a 3D multidisciplinary database of the project and unifies the various sets of information required and used throughout its lifecycle into a common digital environment, reducing or even eliminating the need for the many types of documentation currently in use (Santos & Costa, 2017). As a result, it is a significant enabler for increasing work efficiency by saving time, money, and resources (ISO 29481-1:2016, 2016). This collaborative work environment makes BIM a key player in this digital shift. Plus, by fostering such a collaborative work environment, BIM has become instrumental in developing innovative performance-based design methods (Santos & Costa, 2017). By properly integrating simulation tools, BIM methodologies may finally leverage simulation tools effectively to inform decision-making (Han et al., 2018) and to optimise resources from the early design stages (Collao et al., 2021).

However, despite the wide array of simulation tools available in the AECO industry, most are primarily designed for use in the later stages of the design process (Han et al., 2018). Conversely, there is a notable scarcity of decision-support simulation tools validated for early design stages. Research indicates that building performance optimisation is primarily determined during these early design stages, with over 40% of energy-saving potentials (Han et al., 2018). Thus, it is imperative to integrate microclimate and comfort conditions in the design process as early as possible to avoid potential trade-offs due to uninformed design decisions. Rectifying errors made in the initial design stages is costly and hardly feasible (Ulpiani et al., 2023).

Effective decision-making in this early stage poses several challenges, such as time-consuming modelling, rapid design iterations, conflicting requirements, input uncertainties, and spatial calculations (Han et al., 2018). To overcome these challenges, numerous researchers within the BIM work environment are actively engaged in innovating and refining simulation tools and methods to enhance the efficacy of addressing urban challenges (Hu et al., 2022). This effort includes developing simulation tools that facilitate understanding and predict complex urban phenomena, such as urban microclimate and comfort conditions (Delval et al., 2021). Presently, Computational Fluid Dynamics (CFD) simulations have emerged as the predominant numerical simulation method for outdoor environmental research to estimate urban microclimate conditions with a focus on air/surface temperature, airflow, and relative humidity (Javanroodi et al., 2023; Sola-Caraballo et al., 2023), surpassing wind tunnel experiments and field measurements (Hu et al., 2022; Toparlar et al., 2017). However, CFD simulation tools typically demand the expertise of professional engineers and substantial training, presenting a barrier for urban planners and architects in their adoption (Kaijima et al., 2013). Consequently, CFD simulations are not widely integrated into urban and architectural design practices for studying urban environmental aspects.

Exploring simplified CFD methods and developing light-version CFD tools with enhanced speed and user-friendly interfaces are viable approaches, aiding in the analysis of urban environmental challenges in design practice (Han et al., 2018; Hu et al., 2022; Kaijima et al., 2013). Incorporating CFD methods into architectural design platforms via plug-ins may represent a significant advancement, offering convenience to urban planners and architects (Han et al., 2018). These CFD plug-ins enable geometric model generation, numerical simulations, and result visualisation within their familiar design environments, simplifying the simulation process (Han et al., 2018; Hu et al., 2022; Kaijima et al., 2013).

An increasing number of researchers are employing CFD plug-ins to explore urban environmental issues (see **Section 3**). Consequently, it is imperative to evaluate the reliability and simulation accuracy of CFD plug-ins specifically to ensure reliable guidance for design and research. With a specific focus on evaluating the functionality and effectiveness of CFD simulation plug-ins that can interoperate with BIM design tools, this research aims to contribute to the advancement of the current state-of-the-art CFD-BIM interoperability and provide support for the further use of CFD simulation tools in the BIM design process. A comprehensive review of existing interoperability methods and workflows for microclimate analysis of urban designs is developed and discussed.

In **Section 2**, the methodology, keywords and selection criteria that were applied in the systematic review are presented. In **Section 3**, the existing interoperability approaches between BIM authoring tools and CFD simulation tools are categorised and described. **Section 4** contains a comprehensive analysis of the reviewed application studies using CFD plug-ins for urban microclimate analysis. In **Section 5**, CFD plug-ins collected from the literature review were systematically categorised and compared, evaluating their applicability as decision-support tools in design processes and their interoperability within the BIM environment. Finally, the conclusions are introduced in **Section 5**.

2. Materials and Methods

An extensive and systematic review of the scientific literature on BIM-CFD interoperability is performed. The research methodology in this paper involved sourcing scientific literature from ISI Web of Science, Google Scholar, and Scopus, with SpringerLink providing additional search support. The following keywords were used as sources of search records: "BIM" OR "Revit" AND "CFD" OR "Computational Fluid Dynamics" AND "urban" OR "outdoor" OR "microclimate" OR "comfort" OR "interoperability".

To conduct a comprehensive literature review aligned with the objectives of the present and future research, we focused on selecting application studies of CFD plug-ins with a dual potential on current usability and future research. This means selecting CFD plug-ins that not only address the current needs of BIM professionals, but also can pave the way for future advancements in BIM-CFD integration. To do so, we established rigorous criteria focused on interoperability capabilities to ensure an efficient and relevant selection of works. To be selected, the CFD plug-in must address at least one of the two following criteria:

- It includes direct launchers for at least the most widely used BIM authoring tool in the current AECO industry: Autodesk Revit.

- It is compatible with open data file formats (e.g., IFC, gbXML). This approach broadens the scope of our analysis and enhances the potential for future research to explore diverse interoperability methods (see **Section 3**) beyond the coupling of modelling and simulation software via plug-ins. For instance, these tools can also be examined through the model exchange method, which requires a neutral file format to facilitate data model exchange among different tools.

3. Existing approaches for BIM-CFD interoperability

Over the years, both researchers and software developers have dedicated considerable focus and resources to enhancing the interoperability between computer-aided design and performance simulation software (Østergård et al., 2016). Ongoing research aims to enhance such interoperability and address challenges related to time-consuming modelling processes, interconnected workflow between software, and interdisciplinary collaboration among professionals in the AECO industry and related disciplines (Han et al., 2018). It creates a significant challenge when different stakeholders need to communicate across different BIM software, consequently weakening the integration of different project models and databases (Fassi et al., 2022; Østergård et al., 2016).

BIM developers in the software market have produced various software supporting BIM data exchange across different platforms, ensuring compatibility and interoperability (Fassi et al., 2022). Following the categorisation of simulation programs presented by Citherlet (Citherlet, 2001), this study categorises existing approaches for interoperability between BIM modelling and microclimate simulation tools into four main types (see **Figure 1**).

(a) Stand-alone method

At the most fundamental level, stand-alone methods involve using separate BIM authoring and simulation tools, each requiring its own project model. While straightforward, this approach suffers from inefficiencies due to the need for redundant model creation and manual synchronisation of modifications across different aspect models. Any changes in the project necessitate updates in each model, posing challenges for coordination among design team members. Moreover, the lack of inter-application data transfer can lead to data redundancy and inconsistencies between models. Users also need to familiarise themselves with the interfaces of each program.

(b) Interoperable method

Interoperable methods facilitate the sharing or exchanging of parts or the entire model among the different tools. This can be achieved through either model exchange or model sharing.

(b.1.) **Model exchange** involves packaging and transferring the data model between stand-alone tools using a neutral file format. This reduces setup time but requires updates to individual data models upon project modifications to maintain consistency.

(b.2.) **Model sharing** allows specialised tools to extract data from a single data model, centralising information and simplifying maintenance but requiring complex management. However, this approach remains limited in terms of interactive data exchange during the simulation process.

(c) Integrated method

Integrated methods refer to numerical simulations integrated into BIM software, facilitating information exchange throughout the simulation process. This approach simplifies data management and verification processes, and eases the learning curve for users, as there is only one interface to master. Integrated models can evolve more easily as they are not dependent on external applications, and modifications need only be implemented once.

(d) Run-time coupling method

Run-time coupling connects modelling and simulation tools during simulation, enabling cooperative information exchange. One tool controls the simulation process and requests data from BIM authoring tools as needed. While this approach enhances simulation accuracy and efficiency by allowing real-time data exchange, maintaining data and link consistency can be challenging as each tool evolves separately. This method links BIM authoring tools and simulation tools using APIs or plug-ins.

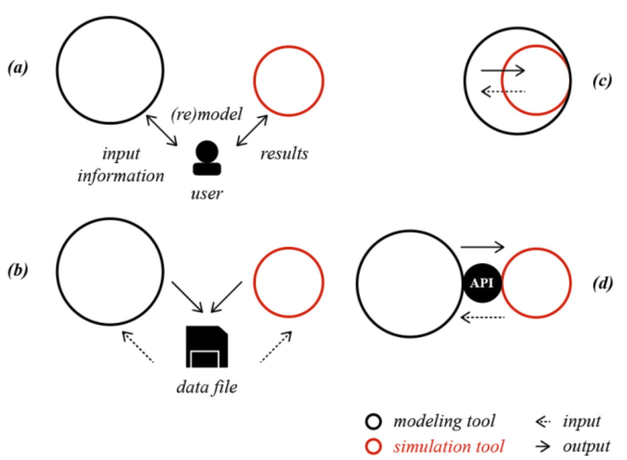

Figure 1. Methods for interoperability between BIM modelling and microclimate simulation tools (Source: Authors´ elaboration based on Østergård et al., 2016)

4. Application studies of CFD plug-ins interoperable with BIM authoring tools for urban microclimate analysis

Table 1 concisely summarises the main aspects of the selected application studies. Below is a brief discussion of their methods, findings, and limitations.

Most studies focused on performing numerical simulations rather than using CFD feedback for design improvement. CFD integration is generally performed at the final stage of the workflow, primarily to assess the impacts of the final design through multi-scale or multi-objective simulations. Very few studies (Liu et al., 2024; Johansson & Yahia, 2020) adopt an application-oriented approach where CFD simulations are leveraged to assess and enhance the original design through iterative feedback. (Johansson & Yahia, 2020) aims to improve the proposed design by addressing insufficient solar access, especially in courtyards. The high height-to-width ratios of streets and courtyards negatively impact daylighting for ground-level apartments and offices. To improve microclimate conditions, they suggested adding vegetation and wind barriers, lowering some buildings for better solar access, and incorporating trees for shade in courtyards, streets, and public spaces. (Liu et al., 2024) outline a systematic approach for interaction between urban microclimate assessment and urban design practices at various stages and scale levels. The current wind environment was analysed using scSTREAM.

Most studies focus on one specific microclimate condition. Only a few develop multi-objective simulations, which require multiple tools to optimise various performance aspects simultaneously, such as combining Autodesk CFD for airflow and Ladybug for thermal comfort (Johansson & Yahia, 2020), or AKL FlowDesigner for wind environment, RADIANCE for solar radiation and STEVEtool for air temperature and humidity (Huang et al., 2024). In (Javanroodi & Nik 2019), the methodology involves generating two high-density and low-density urban models to represent the major urban morphologies of Stockholm. These models were designed to assess the impacts of urban morphology on energy demand and microclimate conditions. The study divided calculations into CFD simulations and EPS, validated through iterations using ANSYS Fluent and Autodesk CFD.

Findings from the reviewed studies emphasise the need for localised analysis and understanding of specific urban or environmental conditions to make accurate predictions. Moreover, the research community has regarded ground-based measurement data as the 'ground truth' for assessing Urban Heat Island (UHI) estimations derived from numerical simulations and satellite data (Huang et al., 2024). Studies have successfully predicted significant environmental changes and impacts, such as pedestrian heat stress (Huang et al., 2024) and urban ventilation patterns (Lau et al., 2023; Khan et al., 2021; Liu et al., 2024). (Huang et al. 2024) even suggest mitigation measures for reducing future pedestrian heat stress in Welsh cities using CFD simulation results. The prediction of significant increases in pedestrian heat due to climate change emphasises the importance of well-informed urban planning and design strategies and the need for urban planners to incorporate heat mitigation strategies into urban designs.

Some application studies used CFD plug-ins to explore and understand the impact of the height ratio and the adjacency of buildings on airflow (Khan et al., 2021) and particulate matter distribution (Ma et al., 2019) through numerical simulations, aiming to guide urban planning and design. This research is essential for informed urban planning and design, as it can significantly affect thermal comfort and air quality in residential areas. By comparing the ventilation characteristics of different urban layouts, urban planners can use CFD simulations to optimise building and urban designs to enhance natural ventilation, thereby improving pedestrian comfort and reducing reliance on HVAC systems for cooling. (Khan et al., 2021) suggest that having varied building heights with gradients in the direction of the northern facades can create the best outdoor wind environment in Najaf city. In (Ma et al., 2019), the methodology involves numerical simulations using Autodesk CFD plug-in to analyse the turbulent flow regulation of adjacent buildings in residential groups.

The studies have validated the effectiveness of these CFD tools in simulating various scenarios and enhancing the impact of different mitigation strategies through optimal design. (Johansson & Yahia, 2020) use CFD plug-ins to perform simulations that assess wind and solar access within urban environments. They examine the urban design proposed for the Nyhamnen area, analyse wind conditions and solar access, and provide suggestions for improving wind control and solar access in specific parts of the area. They also highlight that advanced wind simulations and solar access calculations are essential tools in the early stages of urban design to improve microclimate. Their research aims to develop a more microclimate-sensitive urban design by integrating advanced simulation techniques into the planning process.

Identifying urban ventilation corridors through CFD simulations and optimising urban design can mitigate UHI effects, with successful applications demonstrated in various cities like Taichung (Lau et al., 2024) and Bangkok (Ngamsiriudom et al. 2024). (Ngamsiriudom et al. 2024) also discusses the value of combining field measurements and CFD simulations for informing urban planning decisions related to urban ventilation and UHIs.

The studies also demonstrated that using such technologies and tools for simulation-based assessments can be cost-effective and efficient. For instance, (Lau et al., 2024) propose a method for identifying urban ventilation corridors by integrating remote sensing technology with AKL FlowDesigner. This method enables comprehensive environmental analysis for urban planning without extensive on-ground surveys, making it an accessible option for cities with limited resources. A research gap remains in this field.

Finally, significant challenges are detected in transferring data between design platforms and CFD plug-ins (Hu et al., 2023; Utkucu & Sözer, 2020). (Utkucu & Sözer, 2020) pointed out that the primary issue in transferring models from Revit to CFD analysis is data loss, with only geometry being transferred. This necessitates re-defining building materials in the CFD program. Additionally, extra data for CFD analysis, such as external air volume, requires a third-party CAD tool, making the process time-consuming. In this regard, (Graham et al., 2020) emphasised that plug-ins intended to integrate CFD into design platforms were not originally designed for urban and building design processes. As a result, these tools still need improvements to perform more advanced simulations.

Table 1. Application studies of CFD plug-ins as urban microclimate analysis tools

Ref. (Author(s), Year)	Country	Spatial scale	Modelling tool	CFD plug-in
(Huang et al., 2024)	UK	Neigh	Rhinoceros	AKL FlowDesigner
(Lau et al., 2024)	Taiwan	District	U-Net	AKL FlowDesigner
(Ngamsiriudom et al., 2024)	Thailand	District	ArcGIS Pro	AKL FlowDesigner
(Liu et al., 2024)	China	District Superblock Block Building	-	scSTREAM
(Kim, 2023)	South Korea	Village/ Compound house	SketchUp	AKL FlowDesigner
(Khan et al., 2021)	Iraq	Residential cluster	AutoCAD	Autodesk CFD
(Johansson & Yahia, 2020)	Sweden	District (Harbour area)	AutoCAD + Rhinoceros	Autodesk CFD
(Ganji et al., 2019)	USA	Building	Rhinoceros + Grasshopper+ Python	Autodesk CFD
(Ma et al., 2019)	China	Residential cluster	-	Autodesk CFD
(Javanroodi & Nik, 2019)	Sweden	Neigh	Rhinoceros + Grasshopper	Autodesk CFD
(Yousef Mousa et al., 2017)	Egypt	Courtyard building	AutoCAD	Autodesk CFD
(Naboni et al., 2017)	Switzerland	Building	Rhinoceros	Autodesk CFD

5. Overview of CFD plug-ins applicability as urban microclimate analysis tools

The constant updating or the short lifespan of newly developed simulation plug-ins presents a challenge in finding detailed simulation plug-in application studies for urban microclimate analysis in the early stages of BIM projects (Han et al., 2018; Hu et al., 2022). Thus, research on this topic is still scarce, presenting gaps for in-depth research.

To address the knowledge gap, CFD simulation plug-ins identified from the application studies reviewed were characterised and comparatively analysed in **Tables 2-4**. This comparative review assesses the functionality and applicability of these tools as decision support tools in design processes and their interoperability within the BIM environment. The software capabilities are identified from the evaluation framework of (Vurro & Carlucci, 2024) and gathered from both primary sources, including technical manuals and user guides, and secondary sources, including the review studies of (Albdour & Baranyai, 2019; Naboni et al., 2017); then, grouped into three categories: model processing capacity (i.e., *what geometry and attribute processing they support for generating the microclimatic model*) (see **Table 2**), interoperability capacity (i.e., *what CFD launcher and what import/export formats they support*) (see **Table 3**) and simulation capacity (i.e., *what microclimate variables they can simulate and what outdoor thermal comfort indices they can evaluate*) (see **Table 4**).

The most used CFD plug-ins are Autodesk CFD, AKL FlowDesigner, and scSTREAM. Autodesk CFD is the most frequently used, accounting for 60% of the reviewed application studies.

The widespread popularity of Autodesk CFD may be due to several significant advantages it offers, especially for professionals utilising Autodesk Revit. One of the standout features is the Revit launcher, which allows users to initiate Autodesk CFD directly from Revit. This means that the BIM model can be imported into Autodesk CFD without any need for additional data preparation or exchange files. Such an efficient connection between Revit and Autodesk CFD streamlines the transition from design to analysis, making it a preferred tool for those seeking to optimise their BIM workflows and contributing to its widespread popularity in application studies. Future research should aim to evaluate the integrity of data throughout the assessment process and explore the potential for the plug-in to handle any necessary data pre-processing automatically.

Results from the application studies endorse some critical points regarding its performance and accuracy. Autodesk CFD demonstrates notable strengths in specific conditions, particularly standing out in leeward airflow scenarios and maintaining accuracy at lower wind speeds. This highlights its reliability for simulations that do not involve extreme wind conditions. However, Autodesk CFD faces challenges with higher wind speeds, where prediction deviations become more pronounced compared to experimental data. Moreover, Autodesk CFD's ability to handle complex geometries with unstructured tetrahedral meshes without significant loss of accuracy underscores its versatility. This feature is particularly advantageous for simulating environments without maintaining orthogonal relationships.

The CFD plug-in scSTREAM is less known than Autodesk CFD, potentially making learning harder due to fewer available resources and smaller community support. Nonetheless, scSTREAM stands out in interoperability, featuring a Revit launcher and the most extensive import format support among the three plug-ins reviewed. Additionally, alongside AKL FlowDesigner, scSTREAM can import IFC files, the BIM-standard format. IFC files guarantee data conservation and standardised data exchange by providing an open, standardised file format that ensures consistency across software platforms. This comprehensive data model covers all relevant building information, strengthening semantic interoperability and minimising data loss during transfers. Additionally, IFC files organise data well-structured, using a defined schema to ensure logical organisation and easy information retrieval. On the other hand, when the building group rotates, the geometries and inflow lose a lot of orthogonal relations, resulting in the weakening of the advantage of the structured hexahedral mesh of scSTREAM.

Despite Autodesk CFD being the most used plugin among the reviewed studies (60%), AKL FlowDesigner has been increasingly applied and validated in recent studies. The emergence of AKL FlowDesigner may be driven by new opportunities arising from its potential in terms of computational efficiency (Huang et al., 2024), although it requires further research. According to (Huang et al., 2024), AKL FlowDesigner can complete a simulation for a two-week period (336 hours) for a 1 km-by-1km urban area in just 3 hours, on an ordinary workstation. This is a significant improvement compared to other standalone CFD simulation software, such as ENVI-met, estimated by (Huang et al., 2024) to take approximately 2000 hours to complete a similar task. Such a faster computation might facilitate more dynamic, simulation-based design and planning processes, allowing for continuous testing and improvement of microclimate-sensitive design strategies based on real-time feedback from CFD simulations. Nevertheless, further research is needed to confirm whether AKL FlowDesigner provides the same level of data detail and accuracy as other CFD software. Comparing its performance will help determine if its faster computation times are achieved without compromising the quality and comprehensiveness of the simulation results.

From a general overview of their capabilities, three prominent aspects emerge. Firstly, AKL FlowDesigner stands out in supporting the most essential import formats within the BIM work environment. In contrast, while Autodesk CFD and scSTREAM support a broader range of import formats, they still fail to include some key BIM formats needed for optimal interoperability. This limitation restricts data exchange efficiency, requiring, if any, middleware or third-party CAD tools for preparing and packaging data files in an exchange format suitable for CFD simulation software. This capability will be further assessed in future research through application studies.

Secondly, while all three plug-ins can evaluate indoor comfort indices like Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD), they differ in their ability to assess outdoor comfort. Autodesk CFD cannot evaluate commonly used outdoor indices such as the Universal Thermal Climate Index (UTCI) and the Standard Effective Temperature (SET) index. In contrast, AKL FlowDesigner and scSTREAM can assess the SET index, providing at least some capability for outdoor comfort evaluation. The complexity and variability of outdoor conditions necessitate using specific indices designed to handle a broader range of environmental-based and human-based parameters (López-Cabeza et al., 2022). Using simulation tools that only evaluate indoor indices can lead to significant inaccuracies in predicting outdoor thermal comfort, resulting in oversimplified and unreliable assessments. Incorporating third-party simulation tools for the comfort assessment stage could address this problem, ensuring accurate and reliable comfort assessments of the project.

As discussed in **Section 3**, the CFD plug-in serves as the controller for the simulation procedure, initiating requests to the modelling tool as needed. This setup ensures that only the necessary components of the coupled programs are used, enhancing efficiency in urban environment modelling and simulation. In this regard, all three CFD plug-ins support the input of detailed key urban features from native modelling software, such as urban canyon geometry, building envelope description, and materials. With robust native geometry processing capabilities, these plug-ins could accurately interpret and manage complex urban structures. Furthermore, their effective attribute mapping capabilities could precisely handle a broad set of material properties from the data file provided by the modelling tool. This will enable simulations to reflect real-world conditions, improving the accuracy and reliability of microclimate and thermal comfort assessments.

Table 2. Model processing capacity of CFD simulation plug-ins

MODEL DESCRIPTION		CFD SIMULATION TOOL		
		Autodesk CFD	AKL FlowDesigner	scSTREAM
OUTDOOR ENVIRONMENT	Topography	X	X	X
	Vegetation		X	X
	Waterbodies		X	X
URBAN ENVIRONMENT	Canyon geometry	X	X	X
	Orientation	X	X	X
	Location	X	X	X
BUILDING ENVELOPE	Shape	X	X	X
	Height	X	X	X
	Walls	X	X	X
	Floors	X	X	X
	Tilted roofs	X	X	X
	Building adjacency	X	X	X
	Windows	X	X	X
MATERIAL PROPERTIES	Transmission	X	X	X
	Emissivity	X	X	X
	Specific heat capacity	X	X	X
	Thermal conductivity	X	X	X
	Density	X	X	X
ADAPTATION STRATEGIES	Cool roofs	X	X	X
	Cool materials	X	X	X
	Natural ventilation	X	X	X
	Albedo	X	X	X
	Absorption	X	X	X
	External shadings	X	X	X
	Evaporative cooling		X	X
MODELING TOOLS			X	X

Table 3. Interoperability capacity of CFD simulation plug-ins

			CFD SIMULATION TOOL		
	DATA FILES		Autodesk CFD	AKL FlowDesigner	scSTREAM
CFD LAUNCHER	Autodesk Revit		X		X
IMPORT DATA FILE	Building Information	IFC		X	X
		gbXML		X	
		XML			X
	Design	3DS		X	X
		DWG			
		DXF	X		X
		SKP	X	X	X
		3DM	X	X	X
		OBJ	X		X
		Parasolid	X	X	X
	Mesh	I-deas Universal (UNV)	X		
		PRT	X		X
		STL	X	X	X
	Topography	Shapefile	X		X
EXPORT DATA FILE	IFC			X	
	OBJ		X	X	X
	CSV		X	X	X
	SKP			X	
	DAE			X	
	FBX		X	X	
	XML				X
	STL		X		X
	Shapefile				X

Table 4. Simulation capacity of CFD simulation plug-ins

		CFD SIMULATION TOOL		
	OUTPUT VARIABLES	Autodesk CFD	AKL FlowDesigner	scSTREAM
PHYSICAL VARIABLES	Air temperature	X	X	X
	Wind speed	X	X	X
	Wind direction	X	X	X
	Relative humidity	X	X	X
	Long and short-wave radiation	X	X	X
	Surface temperature	X	X	X
OUTDOOR THERMAL COMFORT INDICES	PMV	X	X	X
	PPD	X		
	MRT	X		X
	SET		X	X

PMV: Predicted Mean Vote; PPD: Predicted Percentage of Dissatisfied; MRT: Mean Radiant Temperature; SET: Standard Effective Temperature

6. Conclusions

This paper offers valuable insights into the current state-of-the-art and future potential of integrating microclimate analysis within the BIM environment using CFD plug-ins for design impact assessment. An in-depth literature review enables a systematic characterisation of the interoperability and applicability of CFD plug-ins, facilitating future tool comparisons. This systematic approach aims to build a comprehensive BIM-CFD interoperability framework, identifying limitations and opportunities for integrating microclimate analysis into BIM design through one of the four approaches discussed.

A detailed review of three leading CFD plug-ins reveals their interoperability, model processing, and simulation capabilities. The results show that the most frequently used is Autodesk CFD, which supports direct launching from Autodesk Revit, making it highly attractive for professionals looking to optimise their BIM workflows. However, this plugin faces challenges with high wind speed simulations and lacks support for outdoor thermal comfort indices. AKL FlowDesigner, noted for its computational efficiency, shows promise in faster simulations, which is crucial for dynamic, simulation-based design processes. While less known, scSTREAM stands out in interoperability with extensive import format support, including IFC files. However, its structured hexahedral mesh loses its advantage in complex geometries.

Significant challenges persist, particularly data loss during model transfers and the limited scope of current CFD application methods. This review identifies the need for future research to explore multi-objective simulations and the integration of CFD feedback for design improvement to inform decision-making and optimise resources from the early design stages. However, BIM holds the potential to overcome these challenges and adopt advanced approaches where CFD simulations are leveraged to assess various performance parameters simultaneously and enhance the original design through iterative feedback. By leveraging BIM's robust parametric modelling and data management capabilities, these issues may be addressed within a genuinely collaborative data environment. Enhanced data exchange methods and adopting open data formats like IFC can minimise data loss, ensuring comprehensive building information is accurately transferred between BIM and CFD tools.

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