http://dx.doi.org/10.11606/gtp.v15i2.161997

ARTIGO

INTEGRANDO SIMULAÇÃO DE ILUMINAÇÃO NATURAL NO PROCESSO DE PROJETO: ANÁLISE COMPARATIVA ENTRE DUAS PLATAFORMAS COMPUTACIONAIS

INTEGRATING DAYLIGHT SIMULATION ON DESIGN PROCESS: COMPARATIVE ANALYSIS BETWEEN TWO COMPUTATIONAL PLATFORMS

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ABSTRACT: Daylighting presents an important role for high performance buildings. Currently, Building Information Modeling (BIM) has excelled in the Architecture and Engineering (A&E) industry as a collaboration and information exchange methodology that generates integrated computational models. Simulation add-ins for BIM tools capable of performing daylighting simulations in a semi-automated way have been developed, thus presenting a more simplified simulation process and favoring the adoption of performance analysis since initial design stages; being a little explored subject. This article aims to investigate the Insight add-in for Revit, focusing on its daylighting features. The workflow, input-output structure and results of Insight dynamic (sDA) and static (illuminance levels) daylighting metrics were analyzed, comparatively to the add-in DIVA-for-Rhino, which simulation engines were considered validated by literature. Simulations on both software used the same model of a reference office space for the city of Belo Horizonte. Results indicate that Insight's favors the daylighting analysis in the initial phases of the design process and allows the verification of code compliances, however determining materials optical properties presents some degree of complexity. Low sensitivity to glasses with low and medium values of light transmittance was noticed in the case study. Evidence of consideration of internal reflections of light rays (ambient bounces) close to 7 may leed to overestimated results in the case of low complexity models. This study intends to contribute to the understanding of the potentials and limitations of both analyzed tools, especially in regard to the specificities of BIM daylight simulation with Insight.

Keywords: Daylighting simulation. Building Information Modeling. BIM. Insight. DIVA.

Fonte de Financiamento:
Agencia de Fomento CAPES e CNPq
Conflito de Interesse:
Declara não haver.
Submetido em: 07/09/2019
Aceito em: 20/02/2020

How to cite this article:

GARCIA, M. S.; SOUZA, R. V. G.; MARTINS, M. L.; VELOSO, A. C. O. Integrando simulação de iluminação natural no processo de projeto: análise comparativa entre duas plataformas computacionais. **Gestão e Tecnologia de Projetos**, São Carlos, v.15, n. 2, p.69-83, 2020. http://dx.doi.org/10.11606/gtp.v15i2.161997

INTRODUCTION

Daylighting is considered as the best lighting option for human comfort and possesses an important role for the performance of biological functions (ALRUBAIH et al., 2013). The efficient use of daylighting can reduce the need for artificial lighting, which accounts for around 20% of the world's energy consumption in buildings (SANTOS; AUER; SOUZA, 2017). Therefore, daylighting predictions in architecture can contribute both to internal environment quality and to the optimization of energy use.

Lately, there has been an effort to integrate modeling and simulation tools, with tools such as the DIVA-for-Rhino (DIVA) (JAKUBIEC; REINHART, 2011), an add-in that integrates Radiance and Daysim calculation models into Rhinoceros (MCNEEL AND ASSOCIATES, 2018). Parallell to this scenario, the use of Building Information Modeling (BIM), a collaboration and information exchange methodology that generates integrated computational models, has excelled in the architecture, engineering and construction (AEC) industry (GHAFFARIANHOSEINI et al., 2017). The concept of BIM arose in the mid-2000s (EASTMAN et al., 2011) and recently, some BIM platform software has implemented add-in tools that provide the possibility to perform building performance analysis within the modeling program interface. In the area of daylighting, tools like Sefaria, Elumtools and Insight 360, are add-ins that can link Revit (a BIM software developed by Autodesk) with daylighting simulation cores (MIRI; ASHTARI, 2019). Specifically, the Web-based tool Insight 360 for Revit was developed in 2015 (GHOBAD; GLUMAC, 2018).

The tool was developed to be used by non-experts professionals (AUTODESK, 2015) and its daylighting engines validation in comparison with Radiance and measured data have been discussed by Dunn et al. (2015). However, despite the wide use of BIM, there is still little research on the usability of Insight 360 (GARCIA et al., 2018 and GHOBAD; GLUMAC, 2018).

This paper then aims to conduct a comparative analysis about the usability of daylight simulations through Insight 360 and DIVA, to verify the main advantages and limits of their use on the architectural professional practice.

THEORETICAL FOUNDATION

BIM and computational simulations for building performance

Ghaffarianhoseini et al. (2017) define BIM as a set of activities based on a computerized object, in which it is possible to work with three-dimensional building representation, on both geometric and non-geometric terms (functional, quantitative and financial); and their relationships.

Different work emphasize the use of BIM tools for simulating building sustainability analysis and they often point out that there is a need to improve the interoperability among BIM platform software and Building Performance Simulation (BPS) tools (CHONG; LEE; WANG, 2017, GERRISH et al., 2017 and NIZAM; ZHANG; TIAN, 2018). The integration between BIM and BPS models is currently addressed in two formats: Industry Foundation Classes (IFC) and Green Building Extensible Markup Language (gbXML). Although these formats are being used by the AEC industry, the IFC scheme can generate loss of specific information and the gbXML has an inability to read complex geometries (ARAYICI et al., 2018). The IFC and gbXML files are usually read by energy analysis software, that works with Thermal Zones which are defined by one-layer surfaces. So, when simulating the energy performance of a BIM based model, users usually need to remodel or simplify the 3D model (MIRI; ASHTARI, 2019). Additionally, there is a problem related to the lack of open-data schemes for performance simulation software (CHONG; LEE; WANG, 2017). The low interoperability between BIM and BPS tools discourage the early collaboration between stakeholders for the development of performance based designs (ARAYICI et al., 2018).

One existing alternative for that obstacle is the implementation of add-ins with simulation engines into BIM platform software, which can contribute to the generation of semi-automated analysis, favoring the early adoption of building environmental analysis on the design process (ELEFTHERIADIS; MUMOVIC; GREENING, 2017). The add-in tools provide performance feedback directly into the modeling interface and may favor the faster evaluation of multiple design alternatives (NEGENDAHL, 2015), mitigating the difficulties of the usual practice, where adjustments in projects entail the need to manually change analysis models, requiring time for revisions and interrupting the design process (ØSTERGÅRD; JENSEN; MAAGAARD, 2016 and CHENG et al., 2018).

Daylighting simulation: summary of principles, main metrics and software

Lighting incidence and distribution in internal environments depends on different design factors such as length, depth and orientation of rooms, openings, surface reflectivity, glass visible light transmittance, among others (GUIDI et al., 2018 and LEE; BOUBEKRI; LIANG, 2019). Daylighting computational simulations require information about buildings geometry and prevailing sky conditions. They use a simulation algorithm or method to calculate sky luminance and interior and exterior illuminance levels (REINHART, 2011).

The metrics used to evaluate daylighting performance can be divided into static and dynamic. The most usual static metric is the illuminance (lux), considered by standards such as the Brazilian NBR 15575-1 devoted to residential buildings (ABNT, 2013). Among the dynamic metrics, UDI (Useful Daylight Illuminance) and Spatial Daylight Autonomy ($sDA_{300,50\%}$) are considered the most relevant. UDI evaluates useful illumination in rooms, in which the minimum and maximum limits were initially 100lx to 2,000lx and later defined between 100lx and 3,000lx (NABIL; MARDALJEVIC, 2005). $sDA_{300,50\%}$ refers to the percentage of a room area that exceeds the minimum illuminance value of 300lx in 50% of occupancy hours throughout the year (from 8am to 6pm) (IES, 2012), being considered in LEED certification (USGBC, 2018).

Daylighting simulators community recognizes Radiance as the main software, given its wide validation against measured data considering different sky conditions and model complexities (REINHART; BRETON, 2009). Radiance uses backward ray tracing as simulation method and simulates daylighting under one sky condition at a time. In order to perform climate based (dynamic) simulations, Reinhart and Walkenhorst (2001) developed Daysim: a Radiance based software, also widely used and validated against measured data (REINHART; BRETON, 2009).

DIVA integrates Radiance and Daysim with Rhinoceros and was initially developed by the Graduate School of Design at Harvard University between 2009 and 2011 for daylighting analysis (GHOBAD; GLUMAC, 2018). In recent times, different researches have used DIVA for daylighting, thermal and energy consumption studies (FONSECA; PEREIRA, 2017 and CAVALERI; CUNHA; GONÇALVES, 2018).

In the BIM context, Insight 360 uses the Lighting Analysis for Revit (LAR) as the simulation engine, which uses the A360 (Autodesk's cloud rendering service) to process the calculations. Simulations are performed with the Multidimensional Lightcuts algorithm, with confidential and patented adjustments, along with bidirectional ray tracing light modeling technique. Simulations are free for Autodesk user who have educational accounts and for other users it is necessary to buy cloud credits (AUTODESK, 2017b and GHOBAD; GLUMAC, 2018).

Comparative studies of workflows between different daylighting simulation software including Insight 360 and DIVA mention Insight 360 main pros: its user-friendly interface, the automation of the analysis model creation and quick single-point daylighting analysis; being considered relevant for preliminary design solution analysis. As Insight 360s main cons are the restriction of available analysis types, the minor control over calculation parameters when compared to DIVA and the lack of integration between daylighting and energy simulations (STOUTZ; CLARO, 2017, GARCIA et al., 2018 and GHOBAD; GLUMAC, 2018). Previous work, however, did not compare the input/output structure in detail, neither the sensibility in results when design parameters are altered in the design process - aspects for which the present work aims to contribute.

METHODOLOGY

The methodology of the present work consisted in the exploratory study of the daylighting performance simulation with Insight 360, considering its use by architects in their professional practice. DIVA was considered to be a reference in this study due to the validation of its simulation engines (Radiance and Daysim) reported in the work of Reinhart and Breton (2009) and Reinhart and Anderson (2006), and to its broad use on academic research.

Daylighting simulations with Insight 360 (version 3.0.0.1 for Revit 2018) and DIVA (version 4.0 for Rhinoceros 5.0) involved 40 simulations in three steps: 1 - preliminary simulations were performed to investigate the input/output structure and simulation processes of both software. 2 - results of Insight 360 were compared to the ones of DIVA for static (illuminance levels) and dynamic ($sDA_{300,50\%}$) metrics with the variation of parameters one-at-a-time. The varied parameters were: sky type, room depth, glass visual transmittance and wall reflectance. 3 – verification of how many ambient bounces (Ab) are used in Insight 360 for the simulations as it is not possible to specify this parameter in the add-in. The third step then evaluated Insight 360 responses of $sDA_{300,50\%}$ against different Ab values in DIVA.

Simulations were made for Belo Horizonte, Brazil (latitude: -19.85 and longitude: -43.95). The model used for the simulations was based on a typical office room for the city (ALVES et al., 2017). The weather file used for Insight 360 simulations was automatically chosen by Revit when the name of the city was given. To know which climate file was chosen by the software, it was necessary to access Autodesk's Green Building Studio (GBS) (AUTODESK, 2018). The SWERA weather file was used to conduct DIVA simulations as recommended by Fonseca, Fernandes and Pereira (2017).

In order to analyze the results of the static metric, decay curves of daylight levels were presented and the mean bias deviations (MBD) were calculated, being the results of DIVA considered as reference. Comparisons were made both visually (using illuminance distribution maps) and numerically (maximum and minimum illuminance values). For dynamic metric analysis, in addition to the comparison of the percentage results, compliances with the IES (2012) were verified: acceptable if $sDA_{300,50\%}$ met 55% of the room area and preferable if it met 75%.

Model characteristics

The office room model was 5.0m x 9.9m x 3.0m, and presented windows on the North and/or the East facades (Figure 1). The model properties considered for the simulations are presented in Table 1 being referred as characteristics of the "Base Models". No surrounding buildings were considered in simulations.

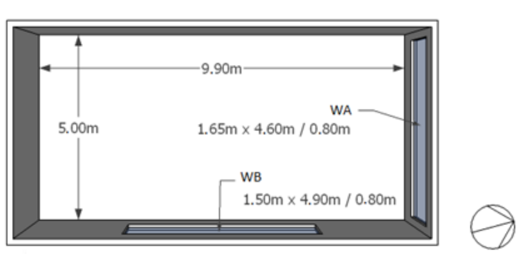


Figure 1: Characterization of the model used for simulations

Source: Top view of the office room. Adapted from Alves (2017).

Parameter	Value
Orientation[1]	N (15º)
Window-to-wall ratio of north facade (WA)	40.5%
Window-to-wall ratio of east facade (WB)	19.7%
Window thickness	6.0mm
Frame percentage	20.0%
Visible light transmittance (Tvis)[1]	90.0%
Roof reflectivity (ρ)	82.0%
Internal and exterior floor reflectivity (ρ)	20.0%
Internal walls reflectivity (ρ)[1]	51.0%

Table 1 - Characteristics of the Base Models

(1) Characteristics of Base Models that have undergone alteration of the one-at-a-time studies.

Source: The authors.

Window A (WA) and Window B (WB) were placed in adjacent facades, allowing the delimitation of different room depths: 9.9m (with WA) and 5.0m (with WB). Thus, three models based on the same geometry were used: the Deep Model (DM, with WA), the Shallow Model (SM, with WB) and Both Windows Model (BWM, with WA and WB).

Simulations description

Generic simulations were performed with both tools for the apprehension of input/output structures and workflows for illuminance and $sDA_{300,50\%}$ simulations. Then simulations were performed with the case study Models. The configurations for static simulations were: analysis plan height of 0.75m and distance between analysis points of 0.30m, considering December 31st at 9:00a.m. For the dynamic metric, the analysis plan height was 0.80m, distance between analysis points of 0.60m, considering the hole year, from 8:00a.m. to 6:00p.m (Insight 360's default).

It was verified that in Insight 360 some simulation parameters are fixed while others are variable. Table 2 shows variable settings in black dots, and fixed settings are presented in white dots.

Table 2: Settings flexibility of metrics parameters in Insight 360

Legend: Variable settings (•), Fixed settings (◦) and Not applicable (n/a). (1) Available sky types: CIE Overcast Sky, CIE Intermediate Sky, CIE Clear Sky, CIE Uniform Sky, Daylight Factor Sky and Perez All-Weather Sky.

Source: The authors.

Simulation parameters	Metrics				
	Illuminance	$sDA_{300,50\%}$	LEED 2009	LEED v4	Solar Access
Sky type[1]	•	n/a	n/a	n/a	n/a
Date and time	•	◦	◦	◦	•
Results unit (footcandles / lux)	•	n/a	◦	◦	n/a
Analysis time interval	n/a	◦	◦	◦	•
Results thereshold (max / min)	•	◦	◦	◦	•
Analysis plane height (inches)	•	◦	◦	◦	•
Distance between analysis points (12 or 72 inches)	•	◦	•	•	◦
Floor to be analyzed	•	•	•	•	•

In what regards Radiance advanced parameters used in DIVA, the configurations were: ambient bounces: 5, ambient division: 1000, ambient sampling: 20, ambient accuracy: 0.1, and ambient resolution: 300; as recommended by Reinhart (2012) for scene complexities considered low (without the presence of sun protection elements). These configurations were adopted in all simulations, except for the third methodological step, in which the number of Ab was varied, as shown in Table 4. In Insight 360, such settings are not accessible.

Static and dynamic simulations in both programs involved the individual variation of parameters: in each set of simulations, only the tested parameter was changed while others remained fixed. For the static simulations, the varied parameters were: room depth (9.9m and 5.0m, considering DM and SM, respectively, with the CIE Clear Sky) and sky types (Perez Sky, CIE Overcast Sky and CIE Clear Sky), using only DM.

On dynamic simulations, the glass visible transmittance (Tvis) and internal walls reflectance (ρ) were individually modified. These parameters were varied with values considered low, medium and high (40%, 60% and 90% for Tvis and 16%, 51% and 82% for ρ, respectively). As the optical properties of materials in Insight 360 are configured by RGB intensity, the values of Tvis and ρ were set based on tables presented by Autodesk (2017b). Table 3 shows RGBs values used for all simulations. In DIVA, those parameters were set manually in a .rad file, obeying the same values.

Input		Variation level	Value	RGB	Observation
Base Models fixed parameters	Roof reflectance (ρ)	-	82%	210,210,210	Base Models
	Internal and external floors reflectance (ρ)	-	20%	50,50,50	Base Models
Variable parameters	Internal walls reflectance (ρ)	Low	16%	40,40,40	Variation studies
		Medium	51%	130,130,130	Base Models
		High	82%	210,210,210	Variation studies
	Visible Transmittance at Normal Incidence (Tvis)	Low	40%	0,0,0	Variation studies
		Medium	60%	7,7,7	Variation studies
		High	90%	209,209,209	Base Models

Table 3 – RGB intensity values considered in Insight 360

Source: The authors.

In third step Ab values tested were: Ab=2 from DIVA default; Ab=5 and Ab=7 for low and high complexities scenes, respectively, as indicated by Reinhart (2012). DM, SM and BWM were used in four orientations, which Azimuths respected the urban tracing of Belo Horizonte, as defined by Alves (2017). The summary of simulations with individual variations is shown in Table 4.

Metric	Parameter	Variations	Model
Static (illuminance)	Sky Type	CIE Clear Sky, CIE Overcast Sky and Perez	DM
	Room depth	9.9m and 5.0m (with CIE Clear Sky)	DM/SM
Dynamic ($sDA_{300,50\%}$)	Glass type (Tvis)	High (90%), Medium (60%), Low (40%)	DM
	Internal walls reflectance (α)	High (82%), Medium (51%) and Low (16%)	DM
	Ambient bounces (Ab)[1]	2, 5 and 7	DM/SM/BWM
	Orientation – Ab test[1]	North (15°), East (105°), South (195°) and West (285°)	

(1) Evaluation of the number of Ambient Bounces - Variations of Ab made only in DIVA.

Table 4: Summary of simulations

(1) Evaluation of the number of Ambient Bounces - Variations of Ab made only in the DIVA.

Source: The authors.

RESULTS AND DISCUSSIONS

Input and output structure comparison

A comparison of the basic input structure and simulation process of Insight 360 and DIVA is presented in Table 5.

	INSIGHT 360	DIVA
Geometry	Modeling architectural elements in Revit (walls, floors, etc.) and definition of "Rooms" (Room command). CAD files can be imported.	3D Modeling in Rhinoceros or in other modeling software compatible with the program, such as Autocad or SketchUp.
Location	A weather file is automatically set for the simulation defined from an online mapping service or from the city's choice in a predefined city list.	Defined by the selection of an EPW (EnergyPlus Weather Data) file. 16 weather files are available, but users can insert new ones.
Analysis plane	Analysis plane perimeter automatically defined from the definition of "rooms". The distance between mesh points: for $sDA_{300,50\%}$ it is fixed at 24 inches (0.60m) and for illuminance, it is 12 or 72 inches (0.30m or 1.82m). Distance from floor: 0.80m for $sDA_{300,50\%}$ (fixed) and free for illuminance.	Built from a reference surface in the 3D model. Users can freely specify the distance between this surface and the analysis plane and the distance between mesh points.
Materials optical properties	Opaque materials: predefined colors can be defined for each material. To set specific reflectance values, users must indicate RGB intensity values. Translucent materials: Tvis is configured from color. There are predefined sets, and to set specific values users must indicate RGB intensity values. Autodesk (2017b) presents a Tvis-RGB conversion table.	There are 28 pre-defined materials available (for wall, floor, ceiling and glass). These must be chosen and assigned to surfaces modeled in different layers. Users can set up new materials in .rad file.
Simulation process summary	Log in to an Autodesk® account (A360), activation of Insight 360 add-in, selection of desired analysis (new or existing). Choice of the desired metric, set parameters (only the variable ones), set the floor to be analyzed, consult simulation price (cloud credits) and send to the cloud simulation service A360. Results are visualized in Revit model by reopening Insight 360 add-in and loading the existing simulation result.	Definition of the location, configuration of the analysis plane, definition of material properties and choice of metrics to be simulated with their specific configurations. Simulation computed on the user's machine. Results are automatically loaded on Rhinocero's model.

Table 5: Input structure and simulation process summary of Insight 360 and DIVA

In Insight 360 the weather file is obtained from a WMO (World Meteorological Organization) database by the indication of a city to the project's Location (AUTODESK, 2017c). The latitude and longitude of the city are compared to the database and the nearest weather station is chosen together with its weather file. If the city is set by using the online mapping service, meteorological stations starting with "59" imply the use of TMY (Typical Meteorological Years) weather archives, while other stations use files from the Autodesk® weather server (AUTODESK, 2017d).

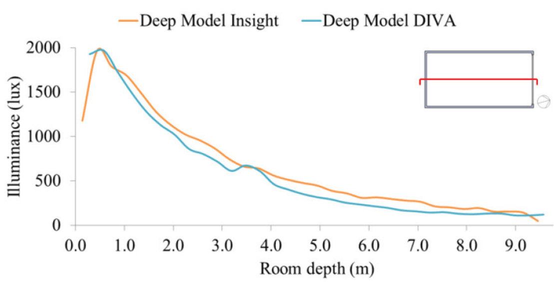
In what regards material properties definition, although Autodesk (2017b) provides tables for converting values of ρ and Tvis to RGB intensities, users have to seek that information in instruction manuals outside the program interface, making the simulation process less automatic.

In relation to the outputs, Insight 360 allows users to get a graphical visualization of the results with 21 predefined and editable display styles, as well as a spreadsheet with numerical results per analysis point (CSV file). Along with $sDA_{300,50\%}$ results, users obtain Design Tips that are based on the Daylighting Pattern Guide (ADVANCED BUILDINGS, 2017), which addresses recommendations related to geometry, glass type and shading elements, to improve the use of daylight. However, attention should be given to the interpretation of the suggested solutions, since they were based on buildings solutions for the United States, which may have different climatic characteristics from the place where the project is designed for. In DIVA, visualizations results are available within three types of color gradation and with CSV files containing results values per analysis point.

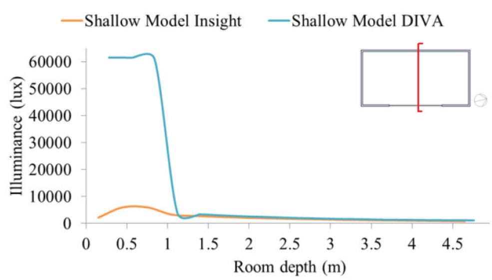
From the results obtained in this phase, it is considered that Insight 360 presents less flexibility of input data configuration than DIVA and greater flexibility of result visualization options. In agreement with Stoutz and Claro (2017), it is considered that Insight 360 presents characteristics that favor its adoption by non-expert architects in the design process, such as the automated definition of weather files, the possibility to configure materials optic properties by color, the ease of performing different simulations in one file and the indication of design tips. As a non-intuitive aspect of Insight 360 for the use of non-expert architects, there is the need to manually load simulation results after its completion. In addition, the difficulty for the precise configuration of parameters such as weather files and materials optical properties are obstacles to greater control of the simulation and can directly interfere in the accuracy of simulations.

COMPARATIVE SIMULATION RESULTS
Static simulations

Figures 2 and 3 refer to the results obtained for different room depths. Figure 2 shows a similarity between the decay curves of daylight levels of the two programs, with a mean percentage deviation of 9%, with the greatest disparity presented in the points closest to the opening (difference of 750lx). The inequality possibly occurred as a function of the definition of the analysis meshes. While in Insight 360 the mesh starts at 0.15m from the wall, in DIVA it starts at 0.28m, although in both programs the input for defining the meshes was the same (0.30m distance between points). In this case, the values close to the window in Insight 360 may have suffered interference of the window sill, resulting in lower illuminance levels.



(2) Deep Model scheme



(3) Shallow Model scheme

Figures 2 and 3: Decay curves of daylighting levels - central line perpendicular to the window.

Deep Model (DM): 9.9m depth and Shallow Model (SM): 5.0m depth. Clear sky, December 21st, 9:00 a.m., orientation N (15 °)

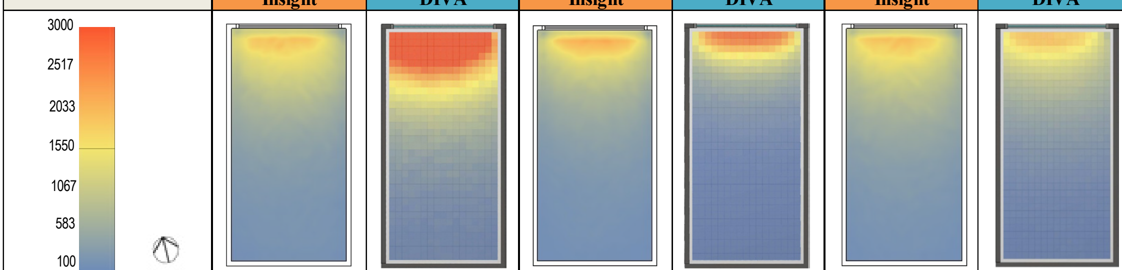
In Figure 3, where there is a higher incidence of direct lighting on the room, there is a considerable difference between results until the approximate depth of 1.10m, with the maximum value provided by Insight 360 being approximately 10 times lower than DIVA's (6.000lx versus 61.544lx). From this depth on, the curves showed more similar behavior, with a mean percentage difference of about 18%. It is inferred that this difference between the curves results from the differences occurred in the area near the window, which influenced the amount of light reflected into the room. Considering that both programs used the same sky type (CIE Clear Sky), in addition to the fact that several points in Insight 360 indicated resultant illuminance values of exactly 6,000lx, it is assumed that this value has been set as maximum illuminance level to be represented in the Autodesk® add-in. Despite the discrepancy, assuming excessive illuminance above 3,000lx according to the UDI metric limit (NABIL; MARDALJEVIC, 2005), the results of both programs evidenced similar guidelines for architects design: the need to develop a protection element to prevent direct solar incidence.

Figure 4 shows the illuminance levels obtained by the variation of sky types. Comparing the results of the two programs, greater similarity in light distribution between the results obtained with CIE skies is noticed. The higher disparity occurred in the Perez sky type, where the maximum illuminance level in Insight 360 was approximately 3 times lower than in DIVA's.

Authors infer that the divergence on the results from the Perez Sky is related to differences between external irradiation data adopted for the calculations of this sky type. While Insight 360 considers the Perez-All-Weather-Sky, using horizontal global irradiation (GHI), direct normal irradiation (DNI) and diffuse horizontal irradiation (DHI), DIVA calculates the Perez sky based only in GHI values, using Radiance's Gendaylit calculation module (AMCNEIL, 2017). Differences between the weather files may also help to explain differences in values calculated by the two programs. To verify the weather file influence in the simulation results representative values of the weather files used in both software were then checked (Table 6).

Figure 4– Illuminance levels with different sky types: December 21st at 9:00 a.m., Deep Model: 9.9m depth, orientation N (15°)

Legend	Sky types					
	Perez Sky		CIE Overcast Sky		CIE Clear Sky	
	Insight	DIVA	Insight	DIVA	Insight	DIVA



	Insight	DIVA	Insight	DIVA	Insight	DIVA
Min. Illuminance (lux)	102	179	76	0	80	179
Max. Illuminance (lux)	1,923	6,265	2,160	2,864	1,975	1,969

	Weather file	GHI	DNI	DHI
Insight 360	GBS_04R20_299004	890Wh/m²	810Wh/m²	93Wh/m²
DIVA	Belo Horizonte/Pampulha-SWERA	623Wh/m²	616Wh/m²	179Wh/m²

Table 6: Weather file information for summer solstice at 9:00 a.m.

Table 6 shows that the SWERA file presents lower values of GHI, although DIVA provided higher internal illuminance levels than Insight 360 when Perez sky was used. An analysis of the mathematical models could contribute to the understanding of how these differences affected the simulation results. Perez (or Perez-All-Weather-Sky) sky model describes, from irradiation measurements, the average angular distribution patterns of sky luminance for all types of sky - from clear to cloudy. It uses direct and diffuse radiation values to parameterize insolation conditions, describing them in a three-dimensional way through the parameters: Z (zenith solar angle), given in radians; e (sky clearness) and Δ (sky brightness), according to Equations 1 and 2 (PEREZ; SEALS; MICHALSKY, 1993).

$$e = [(Eed+ Ees)/Eed+ 1.041Z3]/[1 + 1.041Z3] \quad \text{Eq. 1}$$

$$\Delta = mEed/Eeso \quad \text{Eq. 2}$$

Where Eed is the diffuse horizontal irradiation, Ees is the direct normal irradiation, m is the optical air mass and Eeso is the normal incident extraterrestrial irradiation. As a function of these parameters, the coefficients a to e are calculated to mathematically describe sky conditions.

The Radiance program Gendaylit, used by DIVA, adopts the Perez mathematical model. In addition to the option of using the original parameters of the

Perez sky model (Z, e and Δ), one can report a value of GHI, which is used for calculations by the model of Erbs, Klein and Duffie (1982) (RADIANCE ISE; ADEME EXTENSIONS, 1994). This model calculates the hourly diffuse fraction (Id) from global radiation (GHI) by a relation with an atmospheric clarity indicator (KT), which is the ratio between total (direct and diffuse) daily radiation and daily extraterrestrial insolation incident on a horizontal surface (LIU; JORDAN, 1960 apud ERBS; KLEIN; DUFFIE, 1982). The relationships between Id/GHI and KT were developed from statistical treatments of hourly data from four stations in the United States (ERBS; KLEIN; DUFFIE, 1982).

Erbs, Klein and Duffie (1982) state that this model presents significant uncertainty for the calculation of one-hour diffuse fractions, but that for long-term predictions the calculation is more accurate. Niemasz (2018) indicates the use of the Perez sky with DIVA when users have in loco data measurements and there is interest in modeling a specific sky. Thus, considering situations that exclude in loco measurements, the mathematical model used for the Perez sky in Insight 360 seems to be more precise than the one used by DIVA in the cases of static simulations. Therefore, it is understood that the increase of illuminance levels obtained by DIVA in comparison with Insight 360, although its weather data show lower values of irradiation, is related to the uncertainties arising from the use of the mathematical model described by Erbs, Klein and Duffie (1982).

Dynamic simulations

The sDA results for dynamic simulations when the glass visual transmittance (Tvis), were varied are presented in Figure 5. And the results for the interior reflectances are presented in Figure 6.

Figure 5: $sDA_{300,50\%}$ simulation results: variation of glass type (Tvis)

Deep Model: 9.9m depth and N orientation (15°)

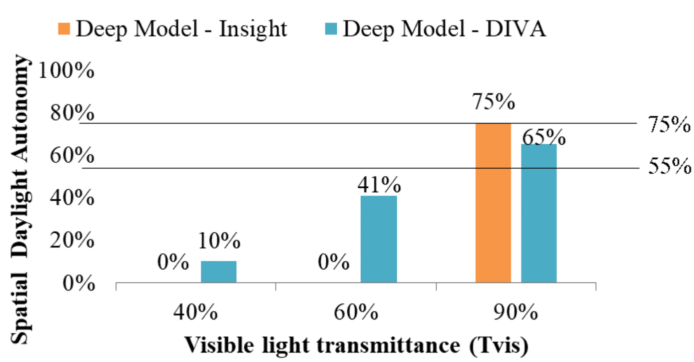


Figure 6: $sDA_{300,50\%}$ simulation results: variation of interior walls reflectance (ρ)

Deep Model: 9.9m depth and N orientation (15°)

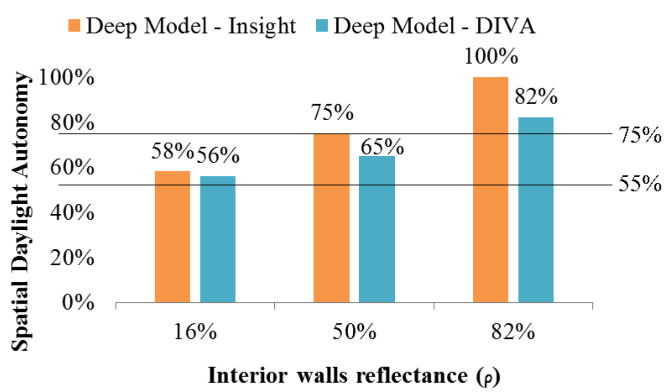


Figure 5 shows significative differences of $sDA_{300,50}$% results between the programs. In the case of low (40%) and medium (60%) Tvis, the null Insight 360 result suggests low sensitivity to glasses with these values. The results obtained by DIVA show a significant influence of this parameter on internal lighting distribution, as expected. From the obtained results, it is understood that the adoption of Insight 360 must be careful when glasses with low values of visible transmittance are used. Nevertheless, in the case of high Tvis (90%), Insight 360 and DIVA presented more similar results, there´s still a difference in attendance levels according to IES (2012): preferable and acceptable, respectively. Those results differ from those by Stoutz and Claro (2017), in which both programs indicated the same classifications for simulations that considered the city of Florianópolis and a 88% Tvis. Radiance advanced settings in DIVA may have influenced the results, but the considered values were not indicated in the authors' paper.

Figure 6 shows that Insight 360 presented higher results than DIVA in all internal walls reflectance variations. The classifications according to IES (2012) were equal in the cases of low (16%) and high (82%) reflectivity, and were different in the case of the medium reflectance (50%). Differences in results raised with the increase of internal walls reflectance, suggesting greater sensitivity of Insight 360 to the variation of this parameter. This aspect may be due to differences in the number of inter-reflections (Ab) considered by both programs, a parameter analyzed in the third step of the present study.

Figures 7, 8 and 9 show the results obtained for Ab values of 2, 5, and 7 varied in DIVA (respectively) and compared to the Insight 360 default, which is fixed and not accessible to users. The simulations considered all Models (DM, SM and BWM) with four orientations (Azimuths of 15º, 105º, 195º and 285º).

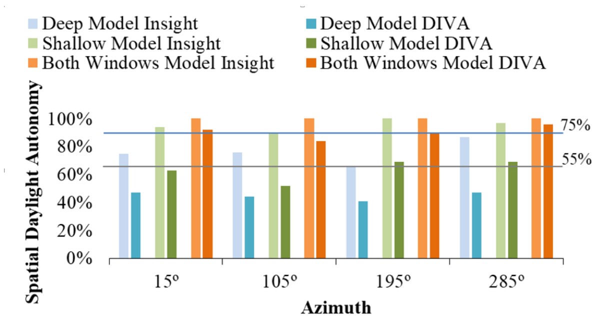


Figure 7: $sDA_{300,50\%}$ simulation results: variation of orientation, Ab=2 (DIVA)

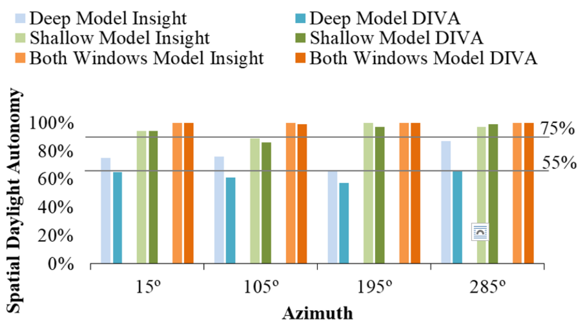


Figure 8: $sDA_{300,50\%}$ simulation results: variation of orientation, Ab=5 (DIVA)

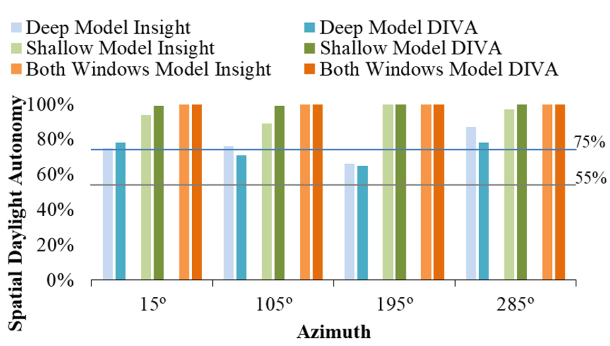


Figure 9: $sDA_{300,50\%}$ simulation results: variation of orientation, Ab=7 (DIVA)

Figure 7 (Ab = 2) shows that Insight 360 provided higher $sDA_{300,50\%}$ values for all orientations and Models, with a MBD of 37%. In regard to the IES (2012) attendance levels, there were cases (mostly in the Deep Model) where results of the same Model reached preferable attendance in Insight 360 while in DIVA it did not attend the acceptable level. Figure 8 (Ab = 5) shows greater similarity between the programs, with a MBD of 6%, but still presenting an overestimation of Insight 360 results accentuated in the Deep Model in all orientations. This result may be due to this model having a smaller glass area, therefore being more sensitive to the number of internal reflections. Figure 9 (Ab = 7) shows the greatest similarity between results, with a MBD of approximately 1%. The only difference between IES classifications (2012) was in the Deep Model with Azimuth 105º, all other classifications being equal for both tools. Thus, by the results obtained in the present study, it is inferred that the number of ambient bounces considered in Insight 360 is close to 7.

In addition to the results of Stoutz and Claro (2017) and Garcia et al. (2018), in which the levels of $sDA_{300,50\%}$ between the programs were similar, the dynamic simulations results of the present work indicate that when using the Insight 360 add-in, there´s a need for caution when simulating glasses with low and medium Tvis, and an overestimation tendency for results in comparison to DIVA, evidenced in the study of internal walls reflectance and ambient bounces variations. This may lead to more permissive classifications in relation to the metric $sDA_{300,50\%}$ from IES (2012). From the present article, along with the guidance of Reinhart (2012), it is understood that the results of $sDA_{300,50\%}$ metric would be more similar between the two programs in cases with high complexity scenes, where 7 ambient bounces would be considered in DIVA.

CONCLUSIONS

Accurate daylighting prediction can highly influence on comfort levels and the energy efficiency of buildings. With the wide use of BIM platform software, the development of Insight 360, an add-in that simulates daylighting within Revit interface, can broaden the adoption of daylighting analysis, subsidizing more informed design decisions. In this paper, an exploratory analysis of the usability of Insight 360 comparatively with DIVA was developed, focusing on data input and output structure and in the similarity of simulation results.

Considering the gains of the BIM methodology such as the information exchange among professionals from the A&E industry, the minimization of errors at the design stage and the possibility of optimization solutions, such as the energy consumption reduction; one of the advantages of Insight 360 is that it works within a BIM platform software. The possibility of simulating different design options in a unique file and the automation of simulation parameter configurations are significant aspects that favor the adoption of Insight 360 by architects in the design process. In contrast, while default settings make Insight 360 easier to use for non-expert users, it presents limitations regarding the configuration of simulation parameters for more precise simulations. The definition of specific optical properties of materials may be an obstacle to the correct use of the tool. However, despite the reduced flexibility, it is considered that Insight 360 input structure allows initial and even normative analysis since the fixed parameters obey standard indications, such as the IES (2012). It was also considered that there is flexibility for illuminance levels analysis, a metric that is considered by Brazilian regulations. It was also verified that the output structure in Insight 360 is more adjustable than in DIVA.

The results of this study pointed out that Insight 360 underestimated illuminance levels compared to DIVA when there was direct solar incidence with the use of the Perez sky. For the dynamic metric, Insight 360 presented low sensitivity to glasses with values of low and medium visible light transmittance and there was evidence of the consideration of ambient bounces close to 7, which may overestimate results in the case of low complexity models.

The findings have a relevant impact on the architects' design practice since differences in daylighting prediction can affect the design choices. Consequently, using one software or another may determine different attendance levels on standards and certifications. For this reason, authors consider that Insight 360 is useful for architects' design practice, but it is necessary that they consider the potentials and limitations of the tool discussed in this paper, to have more reliability in their results.

For more precise analysis, it would be valid to compare the results with field measurements. The limitations of this study include the simulation with only one location, the use of a single low complexity model and non-characterization of an external built environment; aspects that will be contemplated in the continuation of the present research.

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ACKNOWLEDGEMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001 and the National Council for Scientific and Technological Development (CNPq).