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The Applicability of a Newly Developed Revit Add-in for Architects and Urban Designers When Doing Daylight Study from Early Stages to the End of Architectural/Urban Design

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Abstract

Including daylighting strategies from early to the end in the building and urban design process is crucial when it comes to the compliance of environmental certification systems or when the aim is to simply create an interior or exterior space with sufficient access to natural light while still thermally comfortable. Therefore, in this paper, we are going to introduce and discuss a new tool that is an add-in for Autodesk Revit and newly developed by the authors to help architects or urban designers/planners to evaluate daylight condition of exterior or interior spaces by calculating different daylight metrics in different design stages. Since, in a BIM model, most of the information that is needed for daylight analysis are already included in the model, lots of time and human errors can be reduced, if there is a possibility to make direct communication between the BIM model and Radiance that is a physically valid lighting and daylighting simulation software and works as the main calculation core for doing different types of daylight simulations in this add-in. Thus, by saving time and minimizing the mistakes and associated problems when exporting the model for analysis directly from Revit to Radiance and importing the results vice versa, this new add-in makes its users free from using any other third-party software. All in all, the main goal of this add-in is to work as a supportive decision-making tool for those dealing with indoor or outdoor quantity and quality of daylight and its associate threats during architectural design process. Moreover, its results can be used for other assessments such as when doing a thermal comfort analyses or electrical energy consumption in a building. Therefore, it can be helpful for architects, urban designers/planners, and engineers in their everyday works.

Introduction

The European Parliament supports three binding targets for 2030. In addition to a 40% reduction in GHG emissions and at least 30% renewable energy sources, they aim for a 40% target for energy efficiency (EPRS, 2014). Thus, it means that in order to achieve a considerable reduction in greenhouse gas (GHG) emission, there is a need to work on energy efficiency in everything that is related to production or consumption. Since, the building sector responsibility for total carbon emission is usually more or less about 40% (Reinhart, 2014), considering daylight as a means of reducing energy

consumption by providing enough amount of natural light for lighting up interiors should be part of architectural design during the design process. However, when working with daylighting of any buildings or urban realms, not only it is needed to include visible natural light and how to combine it with electrical light, but also, it should not be forgotten its effects on heating and cooling loads, users comfort, and more importantly psychological and physiological health of occupants (Boyce et al., 2003; Heschong, 2002).

In addition to boosting human comfort, human wellbeing, or reducing building energy consumption, another application of using daylight analysis during the architectural design process is when architects want to apply for one of the existing environmental certifications like LEED, BREEAM, etc., or comply with national building regulation such as BBR in Sweden or new European EN 17037 standard. Although such a compliance does not necessarily mean that the result will be energy efficient solution or a totally healthy man-made environment, it is usually good enough to not allow to make a bad solution. That is why a new tool to help them doing such analyses is needed.

Since 1990th, a few simulation tools have been developed to study the daylighting performance of buildings. Many of these tools primarily import a CAD model that is created by another architectural 3D modeling software. Then converting it as a suitable model for daylight analysis and adding all missing information are required in order to do a proper daylight calculation by its daylighting simulation engine. To get the right or acceptable results from the simulations, each tool has its own rules that should be followed by architects or engineers. Generally, the preparation of simulation models is time-consuming and regarding the complexity of the implemented tool, the accuracy of the results and outputs can sometimes change drastically.

Daylight simulation software

Among all the daylighting simulation software that are available in the market, Radiance that is a physically based, backward raytracing lighting simulation tool is the most prominent program that has been used by architects directly or indirectly through other software for around 30 years. Its simulation results are validated for many different types of building geometries and shading devices (Mardaljevic, 1995; Reinhart and Walkenhorst, 2001; McNeil and Lee, 2013). Being an open source

software, its users have much more flexibility to extract whatever they need. Moreover, this software has more capability in handling complex models when comparing with other similar simulation tools in the market.

Generally, there are two types of daylight analyses that can be divided into static and dynamic methods depending on whether they consider a single or a series of consecutive sky conditions. Static analyses are those metrics that are based on a specific date and time, or under a reference sky (like the CIE overcast sky when calculating Daylight Factor). We can argue that the Radiance is the best or at least among the best software that are capable of calculating such metrics for any projects, while, the dynamic metrics are the ones that are based on a calculation for a full or a specific period of year rather than a snapshot of specific condition or at a specific instant. such metrics are climate-based metrics and are based on the typical weather condition of the place (Reinhart, Mardaljevic, and Rogers, 2006). Since it is based on hourly calculation for a specific period, one of the most difficulties about these metrics is that it really takes time to finish its calculation. However, by integrating Daylight Coefficient (DC) approach that “was originally proposed by Tregenza as a method to calculate indoor illuminance levels due to daylight under arbitrary sky conditions” (Tregenza and Waters, 1983) into the conventional Radiance calculation method, it is much easier to estimate daylight availability for a whole year or a specific period of time (Bourgeois, Reinhart and Ward, 2008). Therefore, as soon as we manage to export the 3D model as a Radiance model, Daysim that is a Radiance based software and includes Daylight Coefficient method in its simulation is another software that can be applied to calculate a variety of Dynamic daylight metrics such as Daylight Autonomy, Useful Daylight Illuminance, etc (Reinhart, Mardaljevic and Rogers, 2006; Nabil and Mardaljevic, 2005). Although by using Rcontrib program, Radiance is also capable of doing Dynamic daylight analysis, Daysim is usually a better choice if we are measuring a grid of points on a surface.

Both Radiance and Daysim are Dos-command-based programs. Although such software gives their users much more flexibilities, generally it is not easy for architects and engineers to learn and use them for their everyday works. That is why after around a decade since Radiance is announced for doing daylight simulation, a few graphical user interfaces (GUI) has been introduced into the market. Desktop Radiance, Rayfront and Ecotect (Roberts and March, 2001) were some of the pioneers. Open Studio (Guglielmetti, Macumber and Long, 2011), Diva4Rhino (Jakubiec and Reinhart, 2011), LadyBug (Roudsari, Pak and Smith, 2013), and Sefaria are some other tools that have been developed later and are widely used around the world.

Building Information Model (BIM)

Based on ISO/TS12911, Building (Construction) Information Model (BIM) is defined as “shared digital representation of physical and functional characteristics of any built object, including buildings, bridges, roads,

process plant”. In contrast to other CAD tools, in BIM-based 3D modeling software, not only can we create and modify 3D models and visualize it with different appearances in 2D or 3D, but also the whole model and also each element can separately hold non-graphical information such as geographical information, building orientation, rooms and space types, and types of materials constructing each element, etc. Therefore, most of the data that are needed for daylight calculation already exists in the model, thus there is no need to define them in the simulation software again.

Regarding the growth of implementing BIM 3D modeling software in the Architecture, Engineering and Construction (AEC) Industries, the importance of having a tool that easily communicates between the BIM software and simulation engine is essential when considering to have a user-friendly program is one of our main goals. According to studies done in some countries like UK (National BIM Report, 2017), Malaysia (Bin Zakaria et al., 2013) and middle east (Gerges et al., 2017), Autodesk Revit is the most commonly used BIM-based 3D modeling tools. That is why our main focus has been on developing a new tool under Autodesk Revit Platform recently.

Moreover, both the survey and interviews of an international survey within the framework of IEA-SHC Task 41-Solar Energy and Architecture (SHC Task 41, 2012) strongly indicates the importance of having a user-friendly interface, low cost and integrated to a Cad software as main features of a tool to improve users’ satisfaction. (Kanters, Horvat and Dubois, 2014)

Existing Daylight Analysis Tools for BIM Based 3D Modeling Software

Generally, there are two different ways of doing a daylight analysis for a BIM-based 3D model. The first and the most common way is to export the model as another format such as GBXML, IFC, DWG, DXF, OBJ, etc., that can be read by another daylight/light or energy simulation program like IES-VE, IDA ICE, Diva4Rhino, LadyBug, Ecotect, Dialux Evo, Relux, etc. Then all the calculations, evaluations, and results presentation are done inside that software. Except IFC and GBXML formats, most of the important information that is embedded inside the BIM model such as materials, room functions, and geographical information are lost during importing and exporting the 3D model. In the case of using IFC and GBXML formats, although most of the information are preserved, the software that can handle such files are usually energy/HVAC analysis software like IES-VE and IDA ICE. Since such software only works with Zones that are defined by surfaces with only one layer, all walls, floors, ceilings, roofs, etc., need to be simplified with only one surface. That is why the users of these software usually need to remodel or simplify the 3D models that are imported from BIM based software.

The second method is to do the analysis directly inside the BIM-based software and use all the needed information directly from the model. Regarding the Autodesk Revit as a BIM-based 3D modeling software, programs like

Sefaria, Elumtools, and Autodesk Insight 360 are add-ins that can help architects to directly communicate between Revit and daylight simulation cores. Among above three mentioned programs, Sefaria that is a Radiance based program is more suitable in the early stages of the design process while the other two tools use their own algorithms. Therefore their users are confined with the offered solution and cannot use the whole power of an open source software like Radiance to get what they want when working with it.

Development of a New Daylight Analysis Tool for a BIM Based 3D Modeling Software

Architects can play a key role in achieving low-energy buildings. Since a successful passive design is related to those architectural decisions that are mostly made early during the design process (Kanters, Horvat and Dubois, 2014), we need an analysis tool that can easily support architects to make a correct decision in the early design phase. It means that regarding the rapid change of the design and a large variety of design alternatives, its simulation time should be quite fast and reliable (Østergård, Jensen and Maagaard, 2016). Because of increasing in the *Level of Details* in the journey from early stages to the final design or construction phase, such a tool should be able to handle much higher complexity in the model too. However, regarding the accuracy and efficiency, it should have a possibility to simplify the model as much as possible while keeping its accuracy in an acceptable level.

Regarding all above discussion, the need for a software to handle a BIM-based model in all phases of design and easily communicate between the BIM software and calculation core is essential. Such software should also have a user-friendly interface to facilitate its implementation by architects and engineers.

Therefore, in the following, this newly developed tool and the way of using it by architects and engineers for their daily applications will be discussed further.

AftabRad Add-in for Autodesk Revit

AftabRad that is scripted mainly in C Sharp and IronPython with some commands written in Python and C++, and uses some of Radiance commands inside its interface is an Autodesk Revit add-in that has been developed by the authors to help architects and engineers to estimate the daylight and sunlight availability in and around the building in every stage from early to the end of the design process. This add-in works well with a stand-alone/detached Revit model, Central Model or even cloud-based BIM360 model.

Exporting all geometrical and none geometrical data that are needed by Radiance to do any daylight simulations and presenting the results, all can be done with this add-in inside Revit. Thus, it is an Add-in that can be useful for both advance and ordinary Radiance users that are using Radiance in their everyday works or research. For advanced users, it can be helpful by providing Radiance geometries, and their relevant materials, geographical

position, and orientation by translating the Revit model to Radiance model. Then they can continue their research by doing their custom analyses. However, for an ordinary Radiance user, in addition to above possibilities, they can calculate the most common daylight metrics that are usually asked by most of the building design standards, rules, recommendation or environmental certifications. Moreover, not only can it save the 3D model preparation time, but also it minimizes the mistakes and errors that are related to export to another file. Moreover, except the need for installing Radiance as its daylight calculation core, there is no need to have another intermediate software to do any analyses that is possible by Radiance.

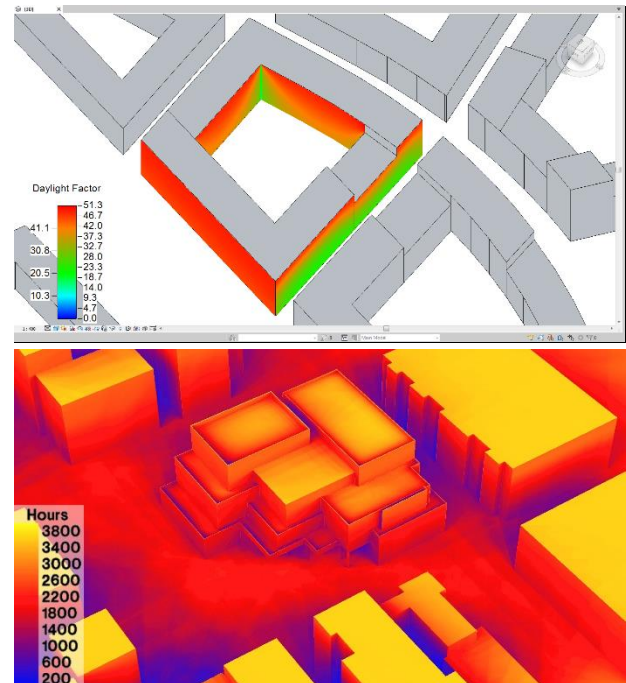


Figure 1: The presentation of Daylight Factor calculation in Revit (the image on top) and Annual Sunlight Hours as a Falsecolor image (the image in the below) by AftabRad add-in

Here it is worth to mention again that in this add-in the calculations core is Radiance. Therefore, regarding the validity of the software, what is important here is the input data. Then, it is Radiance that is in charge of doing the calculation. Thus, the accuracy of its simulations is dependent on the accuracy of its inputs. Therefore, as it is already discussed, most of the input data that are needed for doing any daylight calculation are usually available in the 3D BIM models. Information like geographical specifications, building orientation, room or space types, or material specifications can be extracted from the 3D model in this add-in. However, based on the project needs and which type of metrics we are going to analyze, there is some other information that is needed to be added into the calculation process. For example, the height of surface analysis grids, spacing distances between the grids, their offset from the surrounding walls, the levels and type of rooms that we are interested to analyze, the weather data file of the place, shading behavior of the exterior windows, occupancy schedule and user behavior are some

of them. Therefore, we need to import or add such information directly into the analysis process.

Based on the project needs, the figure 2 shows how, when, and which part of this add-in can help architects during the architectural design process to assess their design against existing rules and recommendations dealing with daylight questions.

To assure the results accuracy and minimizing the calculation time, generally three types of considerations/modification should be taken into account and handled in a quite reasonable way. These three areas can be defined as: the level of details for the exported model, the area of interest to do analysis in the building and finally the material definition for each surface of all the elements in the model. Here, we will explain how it is possible to manage those three areas and some other functions with their relevant interfaces inside this newly developed Revit add-in.

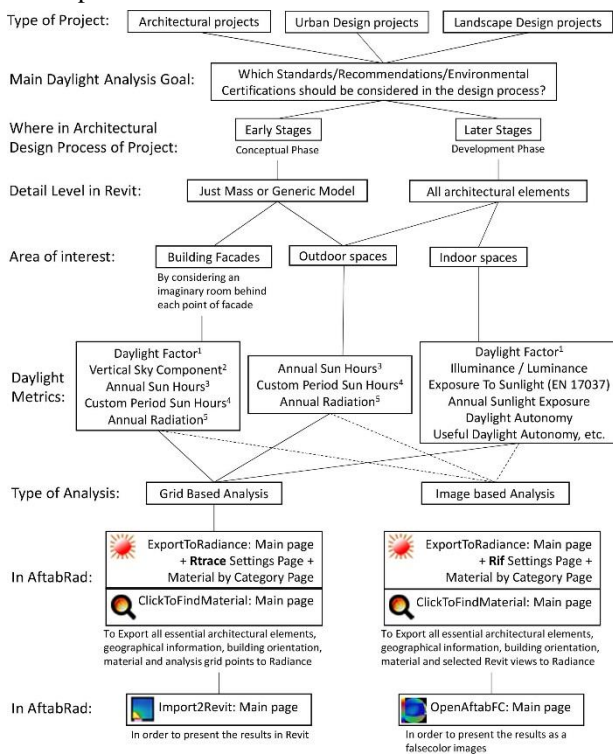


Figure 2: Applicability of different parts of AftabRad add-in during the architectural design process

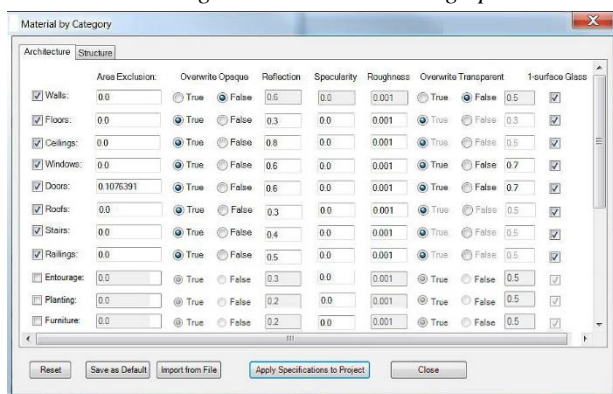


Figure 3: "Material by Category" page in the add-in

Level of Details When Exporting to Simulation Program

Generally, to achieve the results with a good accuracy and in an acceptable time, each energy simulation software suggests an acceptable range of complexity to accurately and efficiently work with. In this add-in, there are six different ways for manipulating the level of details and preparing the model when exporting the 3D model from Revit to Radiance. These methods are as follows:

1. By using a *Section-Box*, it is possible to exclude all the elements that are outside that section box.
2. With the help of the *Isolating*, *Hiding* or *Temporary Hiding* the selected elements or categories in the current view, exporting the only needed elements and skipping the others are easily possible.
3. By selecting which categories can only be exported and which cannot, it is easily possible to filter out unwanted elements such as furniture, electrical equipment, mechanical pipes, etc. The figure 3 shows the "Material by Category" page in the add-in that can help its users to decide on included or excluded categories, and their default optical surface properties values when exporting to Radiance.
4. By adjusting the level of detail when producing triangles from each surface in the model (see the figure 4 as an example) and finally by merging them, we can lighten the exported model in Radiance. In this add-in, the merging algorithm can reduce up to 40% of the exported files size (the below image in figure 4). However, such a file size reduction does not have any effects on the calculation time in Radiance.
5. By converting transparent objects of categories like *Windows*, *Doors*, or *Curtain Panels* into single surfaces that are needed by Radiance, one of the tedious Radiance preparation works can be automatically done by this add-in.
6. By making an area limitation to exclude objects in some categories. For example, in this way, we can exclude all door or window handles in the *Windows* or *Doors* category without a need to hide or delete them in the model.

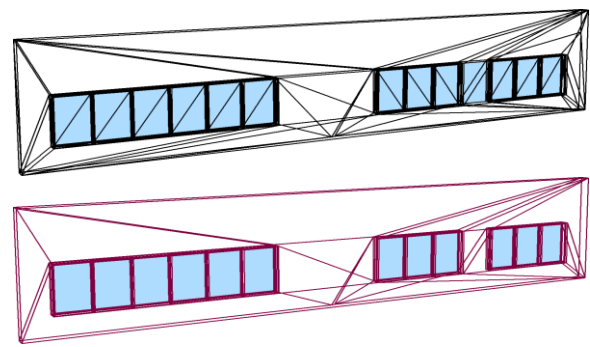


Figure 4: Examples of converting some-Revit elements into triangles when the conversion setting is set to the "lowest level of detail" with and without using the merging algorithm

Selecting Area of Interest/Calculation Surfaces

To create the calculation points that are based on defining their XYZ coordinate positions and directions, this add-in provides five different ways that we can apply one or some of them together. Those five methods are shortly explained in the below:

1. By placing a sensor (as a Generic-Model Revit Family) manually wherever is needed in the model (In figure 5, the top image shows how a Generic Model Revit Family can be worked as a calculation sensor, while the below image shows the Daylight Factor results on the points defined by using such a Generic Model Revit Family.)
2. By selecting the desirable surfaces for analysis (In the figure 6, the image on the top shows how to select calculation surface grid points with the help of Rtrace Settings page, while the below image shows the presentation of the results on the selected surfaces by the ImportToRevit command in the add-in)
3. By filtering the room or space names for the selected levels are calculation grids made by their boundaries (see the top-right image in figure 7 and choose “Rooms in Levels” in “Finding Calculation Surfaces By”)
4. By selecting all floors of the selected levels from which the surface grids are offset (by choosing the “Rooms in Levels” in “Finding Calculation Surfaces Floors” part of the page shown in the top-right image in figure 7)
5. By creating a list file including all the room numbers. Then, it creates surface grids confining by those rooms boundaries (see the top-right image in figure 7 and choose “Room Numbers in File” in “Finding Calculation Surfaces By”)



Figure 5: Creating calculation points with the help of placing one type of Generic-Model Revit Family and presenting its results in Revit with this add-in

In Radiance, the Rtrace program calculates the irradiance or illuminance values of a series of calculation sensor points by tracing rays from them. Thus, the top-left image in figure 7 shows a page in the add-in that makes it

possible for the user to define the Radiance Rtrace parameters that is needed for any sensor points analysis. Moreover, on this page, the user is able to define the offset distance between the grid points and the selected surfaces and the spacing distance between each point on the grids.

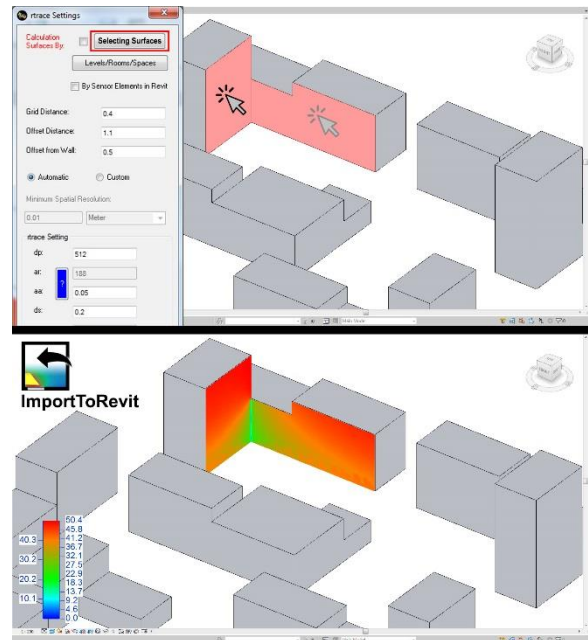


Figure 6: Selecting calculation surfaces and presenting the results in Revit with the help of “Rtrace Settings” and “ImportToRevit” pages in the AftabRad add-in

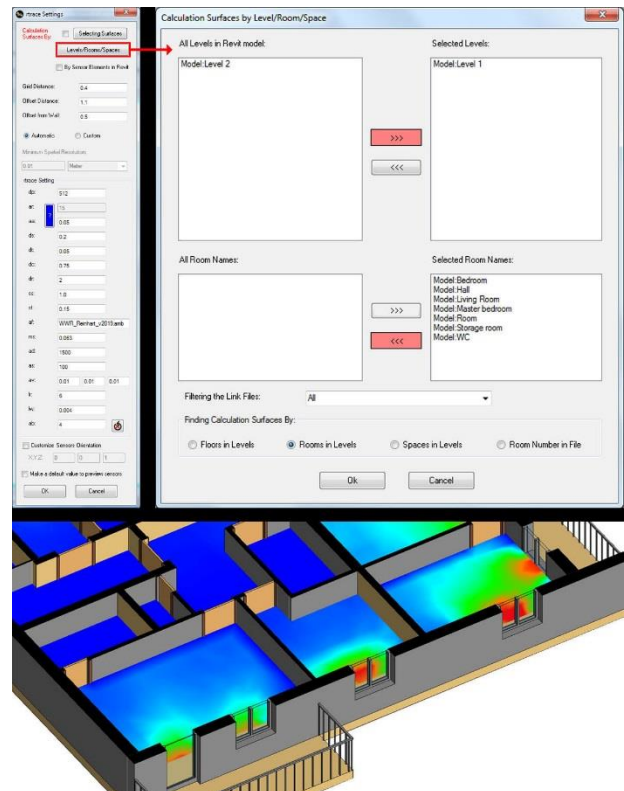


Figure 7: Part of AftabRad add-in (images on top) to help its users to create surface analysis grid points, adjust calculation setting or grid creation parameters, and an example of presenting its results in Revit (the image in the below)

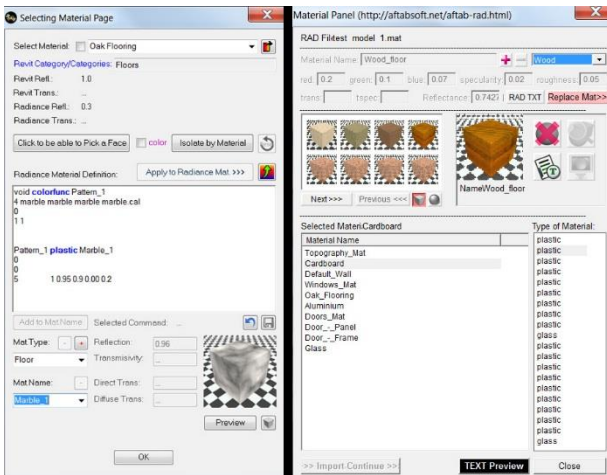


Figure 8: Two pages in the AftabRad add-in to replace Revit material by Radiance material (the left image) or modify the exported Radiance materials before starting the calculation (the right image)

Modifying Material Definition

In order to handle the material definition for each surface of every element in the model, there are three different ways in this newly developed add-in that are briefly explained in the below:

1. Using the Revit material definition and translating its relevant information into an appropriate Radiance material.
2. Applying a default reflection or transmission value (based on opaqueness or transparency in Revit material definition) by defining it in the “Material by Category Page” section for each Revit category (see the image in figure 4).
3. Defining a Radiance material for each specific Revit material that is used in the project before translating it as a Radiance material in the “Selecting Material Page” in the add-in (see the left image in figure 8)
4. Modifying or previewing the Radiance materials in the “Material Panel” (see the right image in figure 8) when the whole 3D model is translated and exported for daylight calculation in Radiance.

Creating Views from Revit 3D Views

Regarding the project needs, sometimes we need to do some view-based daylight analysis such as Glare analysis. Therefore, this add-in has an ability to choose and translate any 3D views defined in Revit as Radiance views. Moreover, in this add-in is there another page to double check the exported views parameters and preview them before starting to render in Radiance that sometimes can be really time-consuming.

In Radiance, in the Rif file, there are some parameters and specifications that can help Radiance to intelligently set parameter values and control the simulation when rendering a specific scene. Therefore, in the figure 9, the left image is the “Rif Setting” page in the add-in that can help its users to not only define and modify the Radiance Rif file parameters that is needed by Radiance but also

select which views the users want to render by Radiance. However, the right image is the “Radiance Views Panel” in the add-in that can help the users to modify the Radiance view parameters (such as view points, view directions, view horizontal and vertical sizes, etc.) of each selected views and preview it, before doing the final rendering by Radiance.

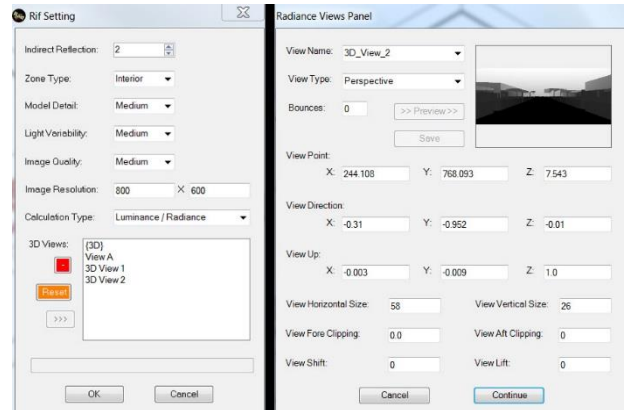


Figure 9: Two pages in the AftabRad add-in to select which Revit views to render by Radiance or adjust its rendering settings (the left image), or modify the selected views parameters before starting the calculation (the right image)

Creating Sky File

Each Revit model has information about the north orientation of the building, and geographical specification of the place like its relevant Latitude and Longitude. Moreover, each Revit 3D view has a sun setting parameters that defines a time of day or a period. Therefore, each 3D view in Revit has all the information that is needed by Radiance to create a sky file. Therefore, all this information automatically extracted from the current 3D view and used by this add-in when exporting the 3D model to Radiance.

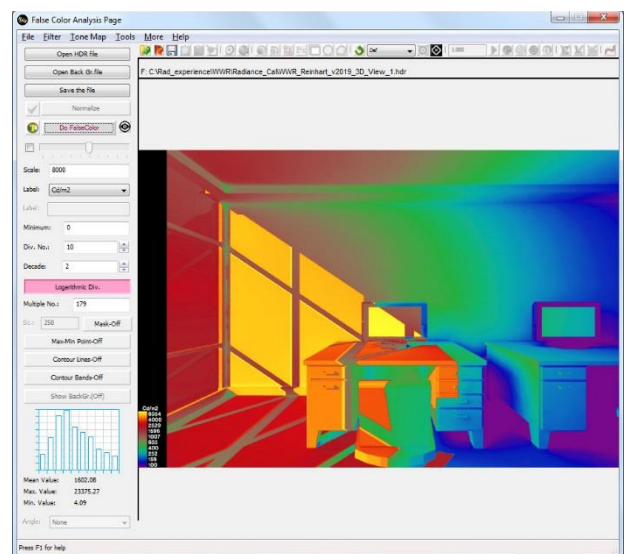


Figure 10: The “FalseColor Analysis” in the AftabRad add-in to help its users to do different types of per-pixel analysis.

Falsecolor Analysis Page

The main goal of developing this page for the add-in is presenting and analyzing the HDR images which are created by Radiance or some other simulation software. A High Dynamic Range (HDR) image is an image in which each pixel corresponding to a realistic luminance, illuminance, radiance, or irradiance value. Therefore, in this page, the users are able to do different types of Per-pixel analysis for an HDR image corresponding to its relevant Revit 3D view. The figure 10 shows an example of creating a falsecolor image from an HDR image that is simulated by Radiance in the “FalseColor Analysis Page” in this add-in.

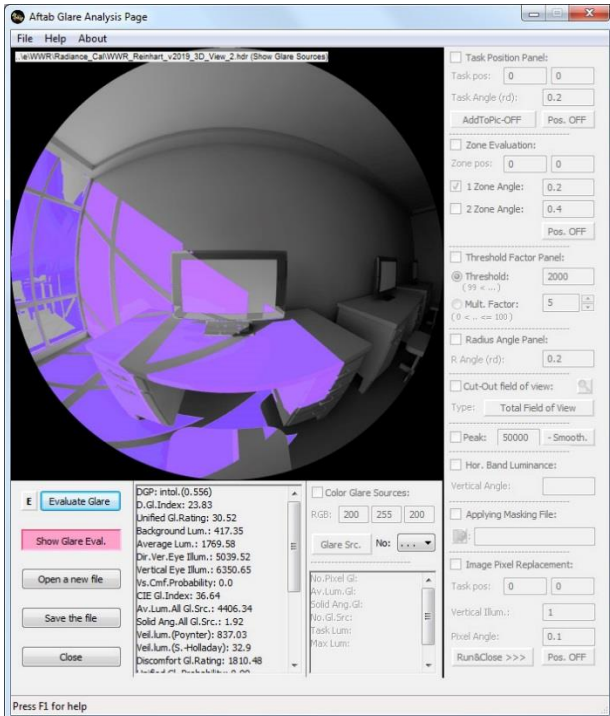


Figure 11: The “Aftab Glare Analysis” page in the AftabRad add-in to help its users to do different types of glare analyses

Evalglare Analysis Page

Here, on this page, different types of glare analyses can be done for each HDR image that is made by Radiance. Its main engines for this kind of analysis is “evalglare” that is a Radiance based tool being developed by Jan Wienold at the Fraunhofer Institute in Germany, or “findglare” that is a Radiance command. Therefore, this page is an interface to detect glare sources and calculate glare indexes such as Daylight Glare Probability (DGP), Daylight Glare Index (DGI), Unified Glare Index (UGI), Unified Glare Rating (UGR), etc. for each Radiance based HDR image.

The image in the figure 11 shows the “Glare Analysis Page” in the add-in that can help its users to do glare evaluation for each scene that is rendered as an HDR image by Radiance.

Radiance Control Panel

When all the files that are needed by Radiance are created, we have an option to open this page before starting to

calculate. This page allows the user to edit and preview the whole or a selected part of Radiance files such as Rad, Rif, Sky and Material files. A good interactive attribute of this tool is that it can help beginners and even the advanced users of Radiance to learn or adjust Radiance-based required parameters or specifications.

Daylight and View Metrics in the Add-in

Considering the existing building regulations, recommendations, or environmental certifications, this add-in can do some of the most common static or dynamic daylight analyses. At the moment, users of this newly developed add-in can measure the following daylight metrics for images or on surface grid points:

- Illuminance
- Luminance
- Daylight Factor
- Radiance or Luminance based Cumulative Sky
- Sunlight Hours
- Shadow Range
- Exposure to Sunlight (based on EN-17037)
- Annual Sunlight Exposure
- Dynamic Metrics such as Daylight Autonomy, Useful Daylight Illuminance, etc., by exporting the 3D model and the other needed data to Daysim 3.0
- View Out (based on EN-17037)
- Visibility Analysis

Regarding the possibility to work with parametric design, this add-in provides a few Dynamo nodes that can calculate all above metrics except those needing Daysim as their calculation core.

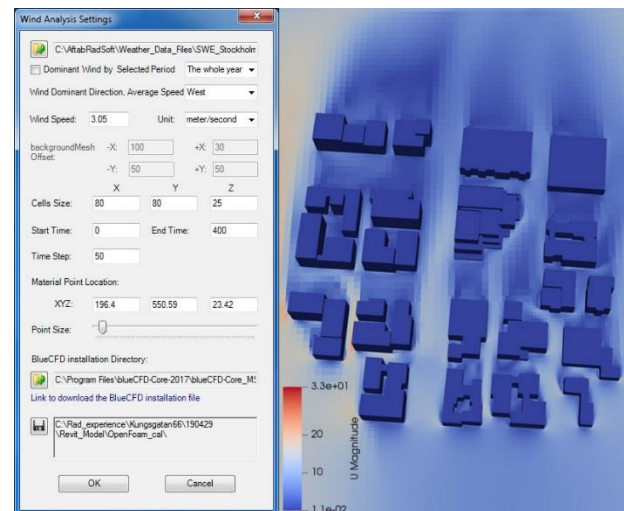


Figure 12: The “Wind Analysis Settings” page in the AftabRad add-in (the left image) and an example of a wind analysis project being visualized by the ParaView software.

Wind Analysis

Finally, there is an additional feature within this newly developed add-in that its main function is to export the Mass, Generic model or Topography elements into

OpenFoam program that is a free and open source Computational Fluid Dynamics (CFD) Simulation Software and do some adjustment for the wind analysis calculation.

In this part of the add-in, architects can easily find the dominant wind direction for the whole year, different seasons, or each month separately by importing the relevant weather data file of the place. At the moment, it only works for the urban realm and it is mostly useful for working in the early stages of the design process.

In figure 12 the left image shows the “Wind Analysis Settings” page in the add-in that can help its users to do a wind analyses for outdoor spaces by defining the dominant wind direction and its average speed together with some other parameters that are needed by ParaFoam. The right image shows an example of a wind analysis project that is visualized by the ParaView software, while the right image shows an example of a wind analysis project that is visualized by the ParaView that is an open source data analysis and visualization software that easily works with ParaForum to show its results.

Future Works

In addition to solving the bugs and errors of the program and developing its interface to make it more and more user-friendly, there are some plans for future developments that are as follows:

- Developing the wind analysis page to be able to work not only in early stages and for urban realms but also later in the design stages and for interior purposes.
- Combining the wind analysis results with Sunlight and Radiation studies to make some kinds of thermal comfort analysis for outdoor spaces.
- Updating its merging three angles algorithm to minimize the exported file size while still keeping the accuracy at an acceptable level.

Conclusions

The main purpose of this newly developed add-in (Aftab RAD) is providing an Autodesk Revit add-in for architects and HVAC engineers to facilitate the communication between the 3D model in Revit and Radiance as a daylight calculation core through some user-friendly and interactive graphical user interfaces. The Primary function of this tool is to translate the 3D model as Radiance objects and export information like geometrical specification, building orientation, material definitions, room/space type and, etc., into Radiance. It has a quite good interface to define surface grids by selecting surfaces, rooms, spaces, etc. It also comprises two other interfaces to do glare evaluation and HDR image analysis. Providing a wind analysis for the users (with the help of OpenFOAM software) in early stages of the architectural design process can be seen as extra function of this tool. In case of using other BIM-based 3D model software such as Archicad or Microstation, it is possible to take advantage of all functions of this add-in

through exporting the model as IFC file and importing it into Revit.

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