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Design of Solar Systems for Buildings and Use of BIM Tools: Overview of Relevant Geometric Aspects

The paper systematizes geometric aspects relevant for understanding design of solar systems. The systematization is based on a review of literature dedicated to various kinds of engineers, including architects, involved in a multidisciplinary process of conceptualizing, designing and realization of PV systems. The understanding of the presented geometric aspects, known as solar geometry, is important not only in terms of finding optimal orientation and most effective tilt of solar modules, but also in terms of adequate geometric modelling of façade elements of a complex shape (as specific photovoltaic modules) in order to be optimally exposed to the sun all over the year. After providing detailed explanations of the main elements of solar geometry using the tools of spherical trigonometry, the paper discusses the integration of the presented geometric concepts in the BIM environments, and refers the example of Autodesk Revit software through its sun study tool. Analysed are functionalities of all interactive components of the 3D solar path representation. A need for more explicit determination of an incidence angle of the sun rays on a tilted surface is stressed. In the conclusion highlighted is the essential knowledge on solar geometry that needs to be acquired during architectural education, so that architects participating in the BIM working environments could be prepared for efficient conceptualization of integrated solar systems.

Keywords: *solar geometry, photovoltaics, BIM, sun study, overshadowing.*

1. INTRODUCTION

Responding to the requests of sustainable development, to the challenges of climate changes and a need to re–duce consumption of energy based on dispensable sour–ces [1], contemporary architectural practice is acquiring the concepts leading to energy efficient buildings. One of such concepts is certainly integration of solar sys–tems, based on optimal utilization of energy coming from sun. Within the solar systems it could be distin–guished passive, active and hybrid ones [2], [3]. Solar collectors and photovoltaic systems belong to the active solar systems. From the geometric point of view, the design of the photovoltaic solar systems is the most demanding, since apart from orientation, inclination and other issues, these systems are highly sensitive to overshadowing. This is the main reason why a set of geometric issues have been overviewed in this paper for photovoltaic (PV) systems.

Aiming at explanation and geometric definition of the relation between a photovoltaic collector/façade module and sun on a given location on earth, the study starts from a heliocentric approach in which the sun is in the centre of the system and earth is revolving with a maximum declination angles of ±23.45° on the summer and winter solstices. Here it also explains the determination of latitude for a given position on earth and its relation with the apparent sun position on the sky during the year. With an aim at a global understanding of the problem, the characteristic positions of sun at the North and South hemispheres are discussed, as well as at the characteristic latitudes as tropics and the Arctic and Antarctic circles.

Shifting into a lococentric approach, in which a given point on earth is considered a centre of the system, highlighted are characteristic angles defining position of sun: solar declination, azimuth, altitude and zenith, solar hour angle, surface (PV) tilt, surface orientation, and the angle of incidence. The difference between legal clock time (civil time) and the solar time (local apparent time) is explained, and the deviation of solar position during the year is illustrated by an analemma diagram.

The study proceeds with an explanation of various kinds of sun-path charts, as well as with examples of the most important online services for generation of such charts for any location on earth. Especial attention has been paid to the problem of overshadowing analysis of a given point on earth, using shadow angle protractor chart. This kind of analysis is of a particular importance in the process of integrating PV systems in a built environment, consisting of many objects of different size and orientation.

Building Information Modelling (BIM) is an emer–ging technology that supports building design, from an early conceptual stage, through the phases of design, documenting and construction, during the period of operation, until the demolition, i.e. through the entire life-cycle of the building. In centre of BIM technology stands

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a 3D model, consisting of intelligent objects that are aimed at representing various elements of building. Defi–ning BIM from the viewpoint of energy efficiency and particularly of solar systems design, it is necessary to stress that important parts of a 3D model are represen–tations of the building built and natural environment. Therefore the 3D model is a geometric representation of designed building and its built and natural environment, serving as infrastructure for linking all other, non-geome–tric information. Application of BIM in design process presumes accessibility and collaboration of different kind of interested participants [4]. In terms of BIM soft–ware, numerous tools have been developed, supporting activity of various disciplines, including the solar studies and building integrated photovoltaic (BIPV) design.

2. SOLAR GEOMETRY

In this section are explained selected geometric issues that are considered essential for understanding functionalities of available solar tools within the BIM platforms. Majority of these issues are related to position of the sun in relation to the earth, so the set of issues belong to the field that some authors define as solar geometry [5,6]. The purpose of understanding solar geometry is improving ability to effectively and confidently use numerous available soft–ware tools that help in determining sun position, sun intensity, shading and overshadowing for particular object on the earth, on particular date and time.

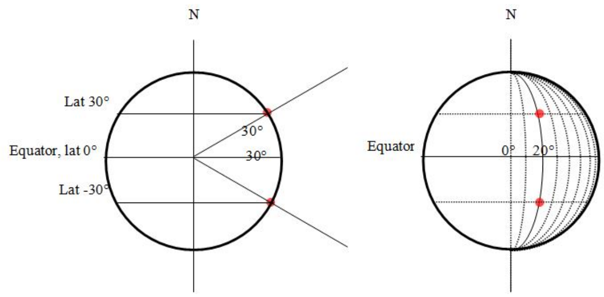

Figure 1. Determining points on the earth at given latitudes (30° and -30°) and longitude (20°)

This part of the study relies on research done by Watson [6], Szokolay [5], Prinsloo and Dobson [7], Hagemann [8] and Kittler and Darula [9-11,12], as well as works by Soulayman [13].

2.1 Geographic location

The base for dealing with solar tools, be it analogue or digital, is understanding that every site on the earth has a unique position represented by angular values called latitude and longitude. While latitude is defined as an angle between the plane of the equator and the line that connects earth's centre and the observed point on the earth (Fig. 1, left), longitude is defined by a set of semi-circular lines (meridians) connecting the north and south pole (Fig. 1, right). The first meridian with the longitude 0° is determined by a convention and is called Greenwich according to the Royal Observatory in Greenwich (UK) that it passes through.

2.2 Position of the Sun

Reviewing the elements of the solar geometry related to sun position it is important to stress that some issues are more suitable to be explained using the heliocentric approach, in which sun is in the centre of the system (Fig. 2), while for some issues it is more useful to acquire geocentric approach (Fig. 1, Fig. 4 left) where the earth is in the centre of the observed system. Finally, for an understanding of the influence of sun on an object at particular location, it is necessary to take the so called lococentric approach when a point at the particular location is the centre of the system (Fig. 4 right, Fig. 5, Fig. 6).

2.2.1 Declination of the earth's polar axis and earth's movement around the sun

For a correct understanding of changes of solar position and intensity during a year, it is important to consider the constant declination of earth's polar axes, of 23° 27´. As some authors do [6], [8], in this study the angular value of earth's declination is considered 23.5°. Therefore, declined at the angle of 23.5° the earth revolves around the sun at a distance of about 150 million kilometres in an almost circular orbit (Fig. 2). The plane of earth's revolution is determined by the sun-earth line and is called ecliptic.

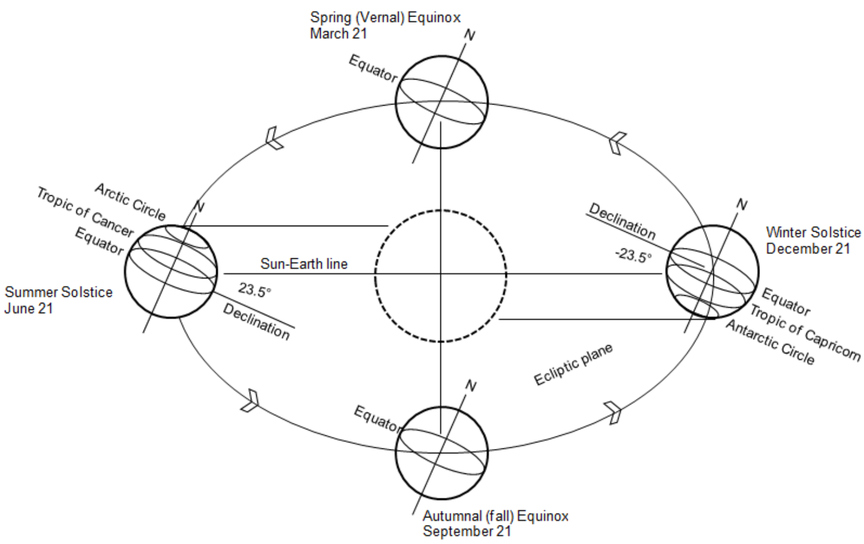

Figure 2. The Earth's orbit as a base for understanding Sun-Earth geometry

2.2.2 Equinoxes and solstices

The earth's revolution around the sun lasts 365.24 days. Since it is a bit more than 365 days which is duration of one year, according to the calendar currently in use, every fourth year has an additional day.

Architects considering the sunlight in general, should be aware of four characteristic positions of earth related to sun during a year. They are represented at the previous illustration (Fig. 2).

The summer solstice (21st of June) is the date when the earth is visible from sun declined 23.5°, so that the northern hemisphere is more exposed to the sun. This position represents the beginning of summer and causes the longest day and the shortest night at the northern hemisphere. At the Arctic Circle, latitude 66.5° (90-23.5), the day lasts 24hours. Opposite, the southern hemisphere is less exposed to the sun, the daytime is shortest and the night is the longest, while locations on the Antarctic Circle -66.5° and below, do not receive any direct sunlight, so that the night lasts 24 hours.

The autumn (fall) and spring (vernal) equinoxes (21st of September, 21st of March) are the dates when the earth has no declination towards the sun, so that sun-earth line and the Equator Circle form an angle of 0°, i.e. the sun rays are parallel with latitude circles. At every point on earth day and night last equally (approx.) 12h and sunrise and sunset mark exact East and West.

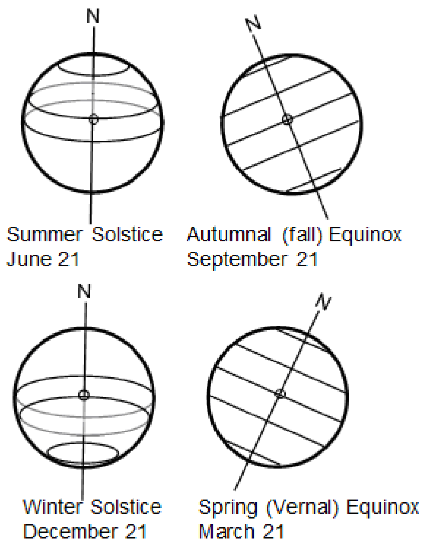

Figure 3. Earth viewed from the Sun on characteristic dates, according to Watson [6]

The winter solstice (21st of December) is the date when the earth is visible from sun declined -23.5°, so that the southern hemisphere is more exposed to the sun, and the daytime at the Antarctic Circle and below last 24 hours and sun at the Arctic Circle and above does not rise at all. For the northern hemisphere this is the date with a shortest daytime and the longest night.

To better understand the issue of earth's declination visible from sun, Watson [6] proposes the illustration above (Fig. 3).

According to Szokolay [5] declination between the equator plane and the sun-earth line (determining ecliptic) for a particular day in the year (NDY), could be expressed as following:

$$DEC = 23.45° * \sin(360°/365 * (284+NDY))$$

where the author uses the more precise value of earth's polar axes declination of 23.45°, and a ratio 360/365 where the full circle of the earth's rotation of 360° has been divided by 365 days, which is duration of a year. The 284 is number of days from the spring equinox, for which the declination is 0°, to the end of the year.

Therefore, the declination for 1st of May, for example, would be:

$$NDY = 31 + 28 + 31 + 30 + 1 = 121$$

$$DEC = 23.45° * \sin(360°/365 * (284 + 121)) = 14.90°$$

2.2.3 Celestial sphere

Celestial sphere is a visual representation of the sky above a selected point on the earth (observer's point, tracking point). It size is arbitrary since, as an imaginary sphere, it serves only for a projection of bodies in the observers sky, including sun, when their distances are unknown or unimportant [7].

A shift from a geocentric to a lococentric view of a selected point on earth, and introduction of a celestial sphere is shown on the following illustration (Fig. 4). The same selected point on earth is observed positioned on earth's surface (Fig. 4, left) and in an idealized horizontal position (Fig. 4, right). It is important to notice that the latitude angle (LAT) is the same as the angle between the zenith line and the plane of the diurnal circle on the equinox days.

2.2.4 Diurnal Circles

The diurnal circles are circles on celestial sphere represented by the apparent movement of the sun during the day. Their position is determined by the location latitude and the declination angle between the earth's equator and the plane of ecliptics (Fig. 4 right, Fig. 5).

The diurnal circles are parallel with the latitude circles, including the equator, and are result of earth's rotation around its polar axis. On the equinox days, for any location on earth, it is visible exact half of the diurnal circle, starting from east and ending at west. At the northern hemisphere, on the summer solstice, the diurnal circle is smaller, but from the examined location it is visible more than a half of this circle, while the sun raises a bit northern than on the east and sets a bit northern than on the west (Fig. 5). On the day of the winter solstice, from the same location it is visible a smaller part of the diurnal circle, while sun raises a bit southern than on the east, and sets a bit southern than on the west.

It is important to stress that on the celestial sphere only the diurnal circle that represents the equinoxes days is the great circle, while the other diurnal circles are small circles. The centers of the small circles however, lay on the same polar axes, normal to the equinox diurnal circle. As for any great circle there's a point P called the pole, in which the polar axes intersects the sphere [14]. The distance between the pole and the corresponding great circle is equal to the radius of the celestial sphere.

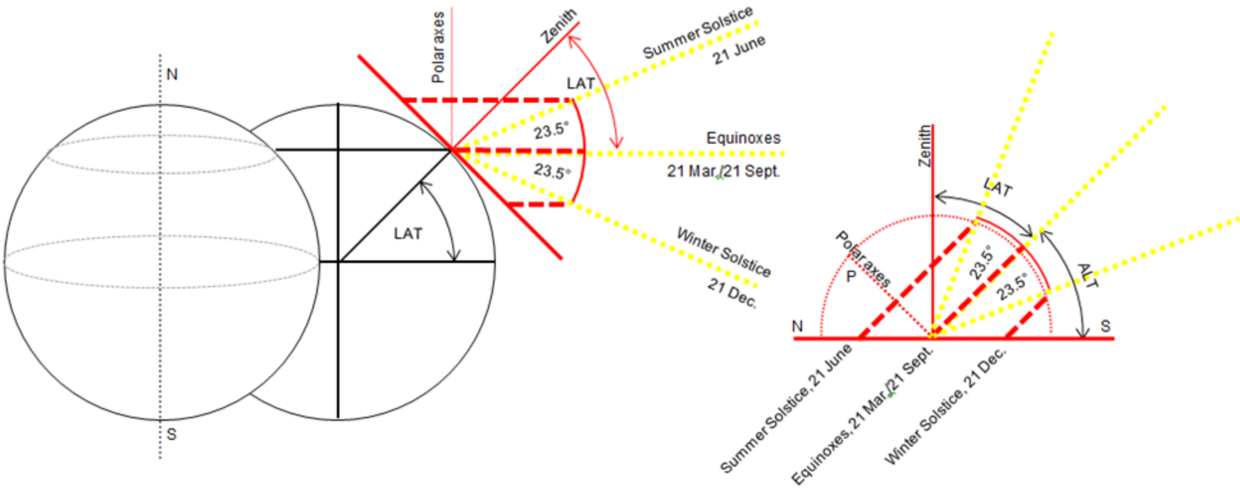

Figure 4. Analysis of the sun position for a selected point on the northern hemisphere, switching from the geocentric to the lococentric approach

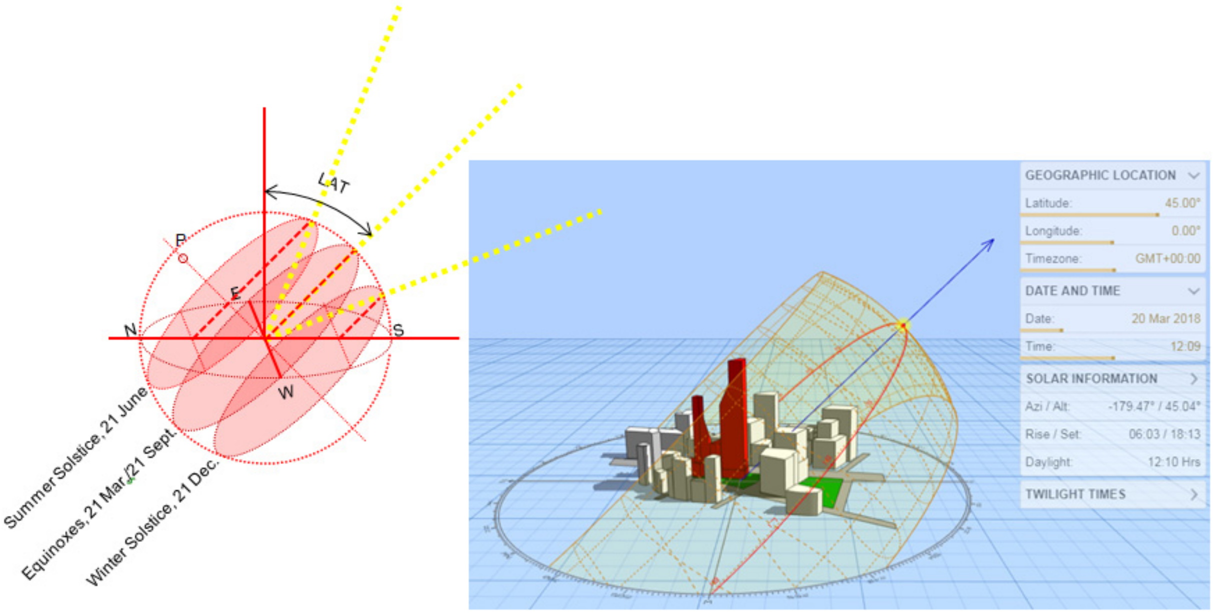

Figure 5. Spatial representation of diurnal circles for a location on the northern hemisphere, Lat. 45°, scheme (left) and the Sunpath 3D simulator (right)

2.2.5 Observing and simulating position of sun for particular locations

When analyzing particular location, it is very useful, if possible, to observe and record position of sun on characteristic dates and times, and then to compare the results with the ones obtained from simulation tools. The illustration (Fig. 6, left) represents position of sun at a location in Vienna, Austria (Lat. 48.15°, Long. 16.40°), photographed on 22nd of March 2018 (one day after the Spring Equinox), at approx. 8AM. The same illustration (Fig. 6, right) shows the Sunpath3D simulation tool [15], set for a similar location, date and time. Using simulations of sun position during the day could be useful in predicting the sun position on the real site.

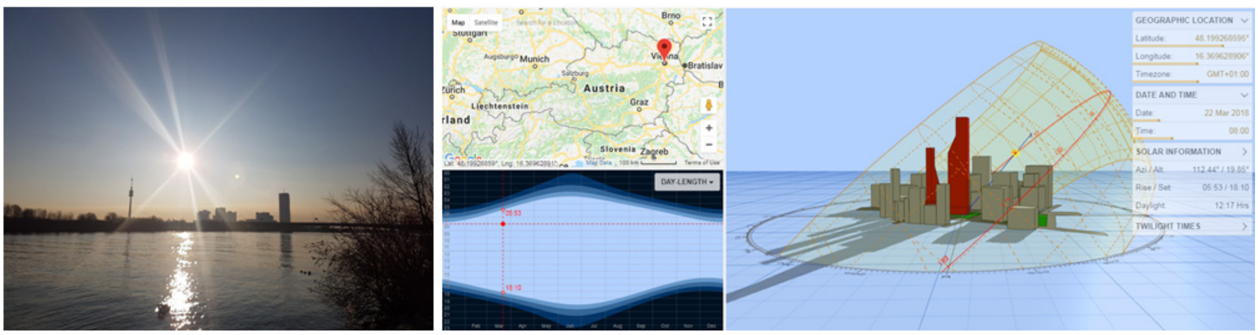

Figure 6. Position of sun in Vienna (Lat. 48.15°, Long. 16.40°) on 22nd of March, 8AM; photography and a simulation in the Sunpath 3D applet (photo arch. Vanja Hajduković)

2.2.6 The hour angle

The hour angle is an angular distance measured in the plane of a diurnal circle. For one hour of the day the hour angle is:

$$360°/24h = 15°/h$$

It is usually measured from the position of sun on the solar noon (Fig. 7, right):

$$HRA = 15° (h-12)$$

where h is the actual hour (24 hour clock), so the morning hour angles are negative and the afternoon hour angles are positive. For 11AM (Fig. 7, right):

$$HRA = 15° (11-12) = -15°$$

2.2.7 Clock time and solar time

It is usual in solar geometry to use the solar time which slightly differs from local clock time due to the division of earth surface in 24 time zones of about 15° each (360 / 24). The solar time is measured by solar noon, the time when sun crosses the local meridian. The solar and the local times are equal only on the reference longitudes; otherwise it is necessary to find the difference between the two as:

$60_{min} / 15° * (LON_{ref} – LON_{real})$.

Therefore for Belgrade this difference would be

60min / 15° * (15° – 20.45°) = -20 minutes, i.e. the solar noon is 20 minutes before the clock noon.

2.2.8 Analemma

Since earth revolves around the sun on an elliptic (almost circular) path and since it does not rotate on a constant speed along all the path, there's a correction in the position of sun for particular dates and times during the year, ranging from -15 minutes in February, to 17 minutes in November. These corrections are expressed by the equation of time (EQT) and represented by a characteristic chart known as analemma [5,15,16].

The analemma chart on the illustration above (Fig. 7, left), represents the equation of time (EQT) on the x-axes, related to the declination between the earth's equator plane and sun-earth line. The chart schema–tically represents the changes in position of sun observed at the same time from a point on earth, during the year. The correction of position of the sun is marked for the 1st of May.

In the available solar simulation tools [15], the equation of time has been calculated and the analemma chart represented on the celestial sphere, for characteristic times of day (Fig. 7, right).

2.2.9 The azimuth and altitude angles

Position of sun on the celestial sphere could be determined by two characteristic angles, azimuth and altitude (Fig. 8).

Azimuth (AZI) is an angle in horizontal plane measured clockwise from north. Thus, the sun positioned on east has the azimuth angle value 90°, on south 180° and on west 270°.

Altitude (ALT) is an angle in vertical plane, between the sun's direction and horizontal. There's another angle in vertical plane called zenith (ZEN), which is supplementary to altitude. It is the angle between vertical direction and sun ray. Therefore:

ZEN = 90° - ALT and ALT = 90° - ZEN

According to the illustration above (Fig. 9) that represents a celestial sphere with the spherical triangle SPZ and the corresponding quadrants:

a – the co-declination angle or polar angular distance of the sun (S) from the pole (P), a = 90 – DEC, cos a = sin DEC and sin a = cos DEC

b – the co-altitude angle or solar zenith distance, the angular distance from the zenith of the celestial sphere (Z) to the sun position (S), b = 90 – ALT, cos ALT = sin b and sin ALT = cos b

c – the co-latitude angle or the angular distance of the pole (P) to the zenith of the celestial sphere (Z), c = 90 – LAT, cos LAT = sin c and sin LAT = cos c

The altitude angle (ALT) is calculated according to spherical cosine rules of spherical triangle sides [17] and the equivalence of angles HRA (Fig. 10):

cos b = sin ALT = cos a * cos c + sin a * sin c * cos HRA

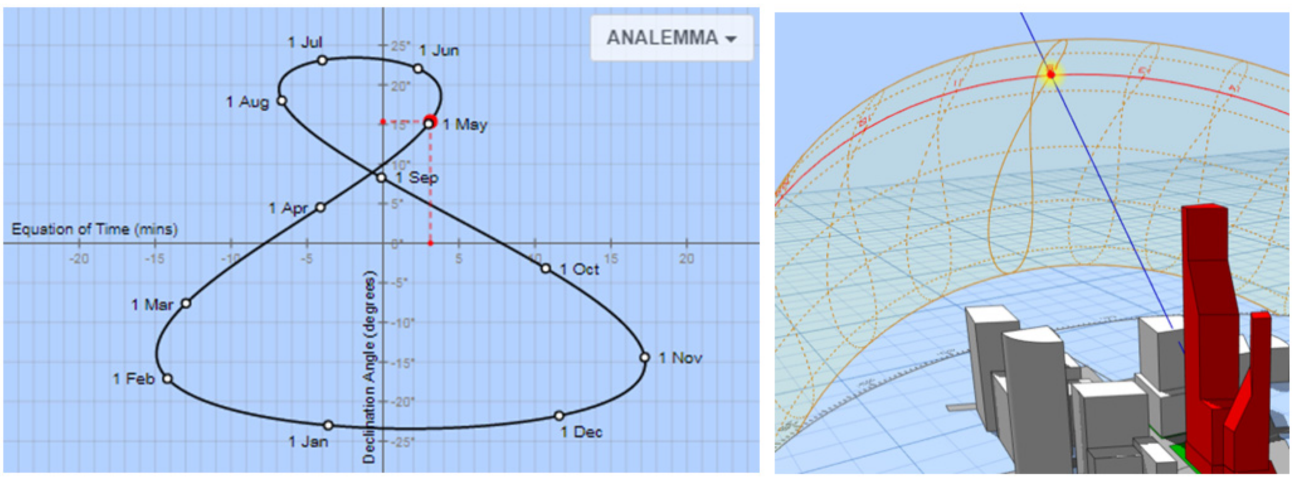

Figure 7. The analemma chart (Sunpath 3D simulator)

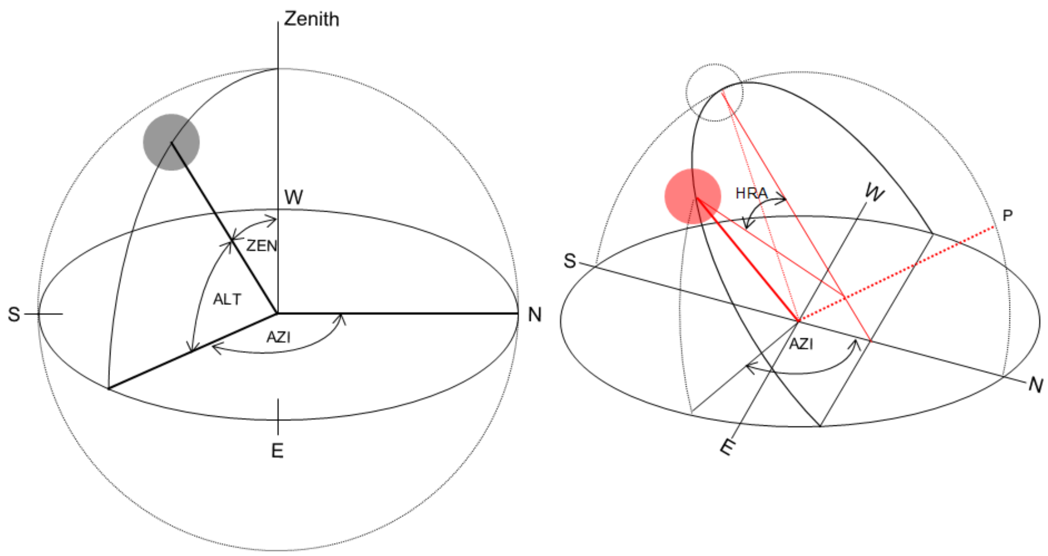

Figure 8. Definition of solar position angles - altitude (ALT) and azimuth (AZI)

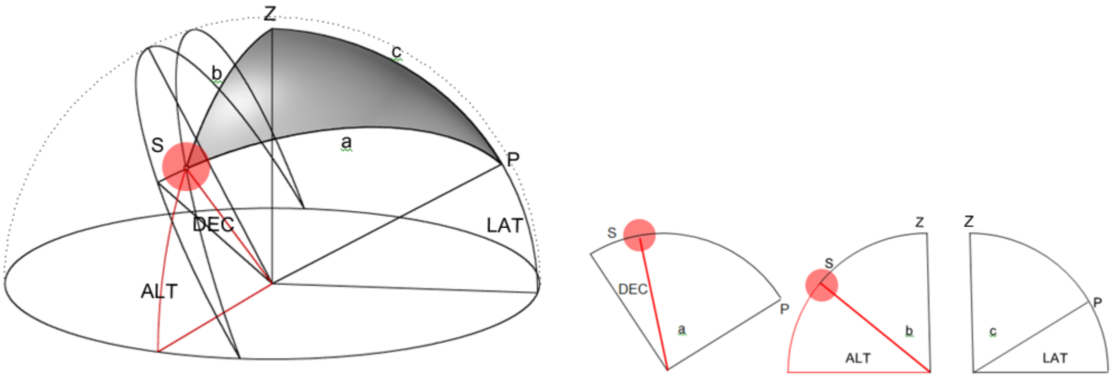

Figure 9. The spherical triangle SPZ and the overview of complement angles a-DEC, b-ALT and c-LAT in the corresponding quadrants

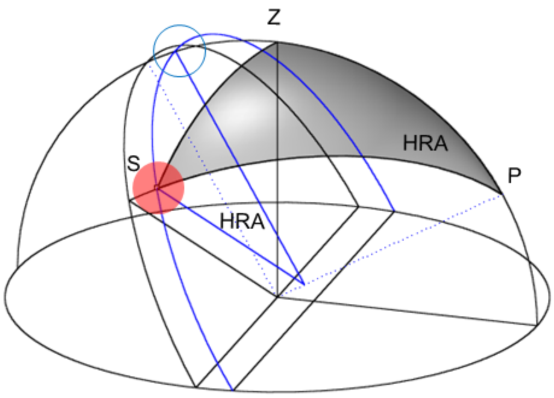

Figure 10. The position of the hour angle HRA on the spherical triangle SPZ

sin ALT = sin DEC * sin LAT + cos DEC * cos LAT * cos HRA

ALT = arcsin (sin DEC * sin LAT + cos DEC * cos LAT * cos HRA)

The azimuth angle (AZI) is calculated according to the same rules:

cos a = sin DEC = cos b * cos c + sin b * sin c * cos AZI

sin DEC = sin ALT * sin LAT + cos ALT * cos LAT * cos AZI

cos AZI = (sin DEC – sin ALT * sin LAT) / (cos LAT * cos ALT)

AZI = arcos ((sin DEC – sin ALT * sin LAT) / (cos LAT * cos ALT))

The azimuth angle could also be calculated using the spherical low of sines [17]:

sin AZI / sin a = sin HRA / sin b, sin AZI / cos DEC = sin HRA / cos ALT

sin AZI = cos DEC * sin HRA / cos ALT

AZI = arcsin (cos DEC * sin HRA / cos ALT)

Szokolay also proposes and explains in detail an alternative calculation of the azimuth angle based on the planar geometry [5], pp. 33:

cos AZI = (cos LAT * sin DEC – cos DEC * sin LAT * cos HRA) / cos ALT

AZI = arcos ((cos LAT * sin DEC – cos DEC * sin LAT * cos HRA) / cos ALT)

2.2.10 The sunrise time and the azimuth of sunrise

Sunrise hour angle (SRH) is derived from the altitude angle equation, presuming that at the time of sunrise, the value of the altitude angle is 0:

sin ALT = sin DEC * sin LAT + cos DEC * cos LAT * cos HRA

cos HRA = (sin ALT – sin DEC * sin LAT) / (cos DEC * cos LAT) and sin ALT = 0 (at sunrise)

cos HRA = (0 – sin DEC * sin LAT) / (cos DEC * cos LAT) = - (tan DEC * tan LAT)

HRA = SRH = arcos (- tan DEC * tan LAT)

Sunrise time (SRT) is calculated based on the equation of sunrise hour angle:

HRA = 15° (h - 12) = arcos (- tan DEC * tan LAT)

h = SRT = 12 - arcos (tan DEC * tan LAT) / 15

Sunset time (SST) would then be:

h = SST = 12 + arcos (tan DEC * tan LAT) / 15

Azimuth of sunrise (SRA) is here presented according to Szokolay [5]:

SRA = AZI = arcos ((cos LAT * sin DEC – cos DEC * sin LAT * cos HRA) / cos ALT)

SRA = arcos ((cos LAT * sin DEC – cos DEC * sin LAT * (- tan DEC * tan LAT)) / 1)

SRA = arcos (cos LAT * sin DEC + sin DEC * sin LAT * tan LAT)

2.2.11 The astronomical day length

Markvart and Castener [18] stress the importance of calculating the astronomical day length (ADL) for architectural design:

ADL = SST – SRT = (12 + arcos (tan DEC * tan LAT) /15) – (12 - arcos (tan DEC * tan LAT) /15)

ADL = 2 * arcos (tan DEC * tan LAT) /15

2.3 The angle of incidence

The angle of incidence is the angle between the sun beam and the normal of the tilted surface. It is calculated according to cosine rule of spherical triangle SNZ sides (Fig. 11), where HSA angle is the azimuth difference between the orientation of the tilted plane (azimuth of the surface normal) and the sun azimuth:

cos INC = cos TIL * cos b + sin TIL * sin b * cos HSA

cos INC = cos TIL * sin ALT + sin TIL * cos ALT * cos HSA

INC = arcos (cos TIL * sin ALT + sin TIL * cos ALT * cos HSA)

For a horizontal surface cos INC = 1 * sin ALT + 0 * cos ALT * cos HSA = sin ALT, INC = 90° - ALT. For a vertical surface cos INC = 0 * sin ALT + 1 * cos ALT * cos HSA = cos ALT * cos HSA.

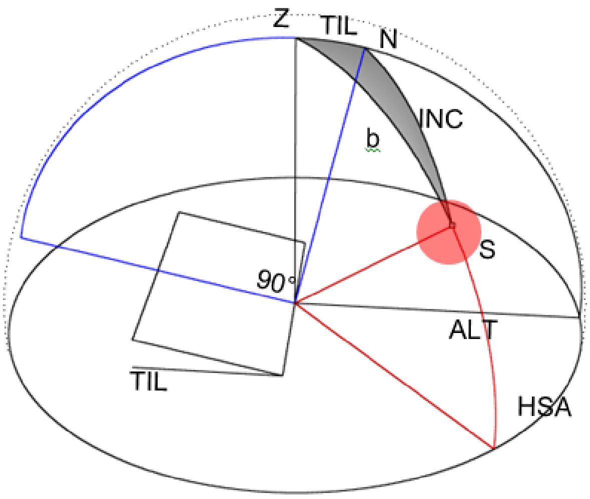

Figure 11. The spherical triangle SNZ and the angles INC, TIL and complement b-ALT

2.4 Sun-path diagrams

Although very powerful 3D sun-path simulators exist nowadays, it is still useful to understand information that could be obtained from 2D sun-path diagrams. First of all, there are two types of 2D sun-path diagrams – circular and Cartesian.

The circular sun-path diagrams could be equidistant, orthographic and stereographic. The construction of the three kinds of diagrams with the examples of sun-paths for the latitude of about -30° (southern hemisphere) is given on the following illustration (Fig. 12). On all the three diagrams the circular lines represent the characteristic altitudes of 0° (outer circle), 15°, 30°, 45°, 60° and 75°(inner circle). The red lines represent the diurnal circles on characteristic dates.

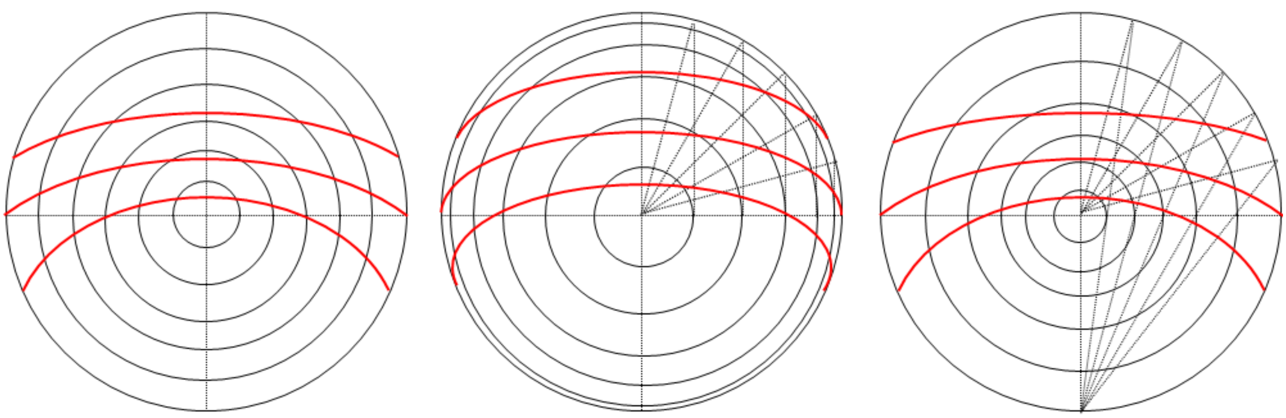

Figure 12. Equidistant (left), orthographic (middle) and stereographic (right) sun-path diagrams

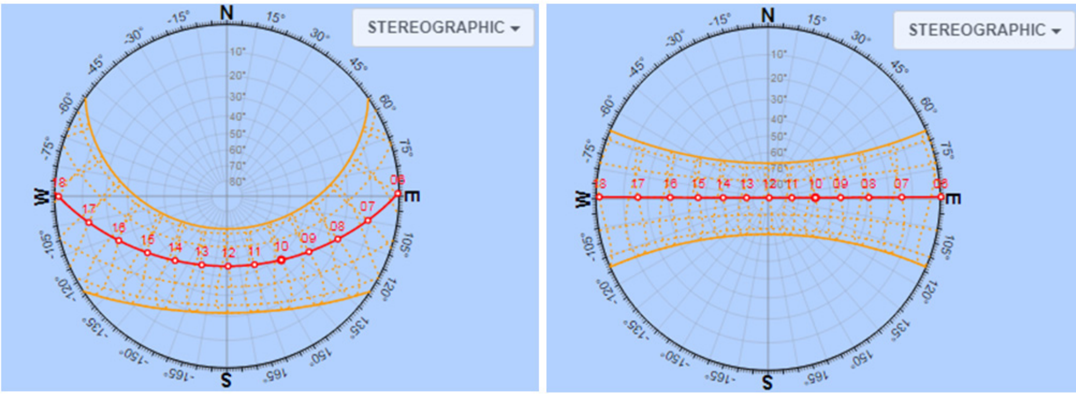

Figure 13. The stereographic sun-path diagrams for Belgrade (Lat 44.5°, Lon 20.45°) left, and a location on Equator (Lat 0°) right

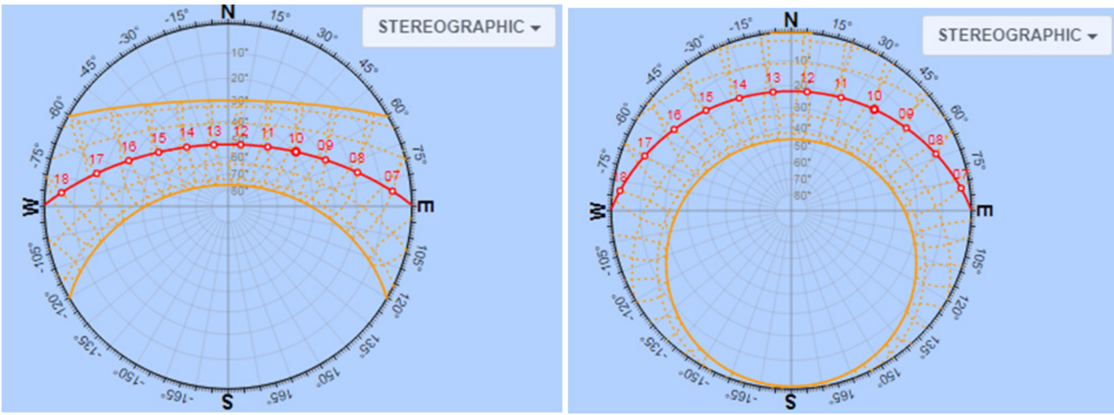

Figure 14. The stereographic sun-path diagrams for Auckland (Lat -37°, Lon 174°) left, and a location on Antarctic (Lat -67°) right

The illustrations above represent the stereographic sun-path diagrams for characteristic locations, Belgrade (Fig. 13, left) on the Northern hemisphere, Equator (Fig. 13, right), Auckland (Fig. 14, left) and Antarctic (Fig. 14, right) on the southern hemisphere.

2.5 Shadows and overshadowing

The shadows resulting from the sun rays are calculating for a selected day during the year, and a specific time. The calculation of shadows is based on the gnomonic pro–jection used from the ancient times [19-22]. The illus–tration below (Fig. 15) shows a stick (gnomon) in an ob–served point for which a celestial sphere has been created with the equinox diurnal circle defined (the black diurnal circle). The sun positioned on a diurnal circle (the red cir–cle) representing particular two days of the year, is casting a ray (the red line connecting the sun S and the point A.

A parallel ray is projecting the end of the gnomon B on the horizontal plane (point B´), defining the gnomon shadow.

The blue arc represents the movement of the gnomon shadow on the horizontal plane, during the observed day. This technique has been used in designing sundials [23,24].

Regarding the shadows on architectural objects that occur as a result of sun rays, which is an issue really critical for an efficiency of the PV systems [25], it is important to distinguish them from the effect of shading and overshadowing [26], [27]. While the shaded surfaces are those not receiving any direct sun rays, the difference between shadows and overshadowing is shown on the Fig. 17. The illustration on the left side represents a house with a shadow cast on the spring equinox afternoon (1PM), and the illustration on the right side represents the same object with an overshadowing effect from the chimney shown through irradiance calculation. Overshadowing is resulting from a movement of a shadow in a given time frame and is calculated statistically. For a better understanding of the overshadowing effect for a given point, it might be beneficial to use the Dynamic Overshadowing tool [28] that is available as an online applet (Fig. 16).

It is usual to examine the shadows for characteristic days, i.e. for the winter solstice when the sun is at its lower position on the sky (at the northern hemisphere), as well as for the summer solstice, when the sun is at its upper position on the sky (at the northern hemi–sphere).

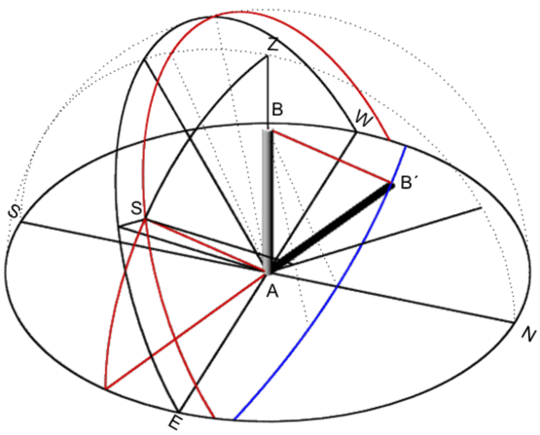

Figure 15. The principle of gnomonic projection in construction of cast shadow

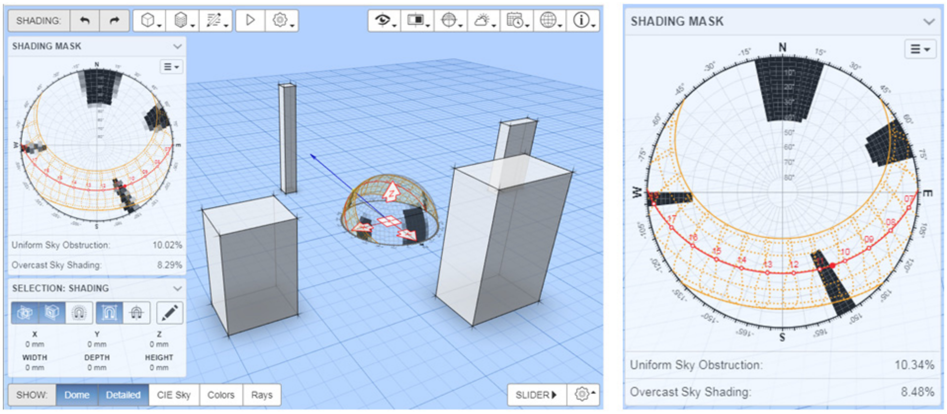

Figure 16. The Dynamic Overshadowing tool by Andrew Marsh showing the overshadowing for a selected point

3. SOLAR GEOMETRY IN BIM SOFTWARE

The concepts of solar geometry presented in the pre–vious section are integrated in majority of available BIM software. Although widely available [29], and sometimes highly specialized for the domain of photo–voltaic design [30,31], these powerful tools still require a deep unders–tanding of geometric principles behind, so that they could be efficiently validated [32] and confi–dently applied.

3.2 Geo-location of project site

It is a standard functionality of BIM software nowadays to allow determining a real location of building site for architectural projects. This means that a project is virtually positioned at a precise latitude and longitude, for which the sun position could be accurately calcu–lated for a chosen date and time of the day. Choosing a real geo-location of an architectural object however, is not enough to perform any kind of solar studies, until the right orientation of the object on the particular location is defined.

3.3 Determining true North

Architectural models, if orthogonal, are usually created so that their facades face east, south, west and north orien–tations. It is important to remember that this is the so called "project north" orientation which is in majority of cases not a real orientation of the designed object. The real orienta–tion of the model is defined based on geodetic surveying digital documents and normally pre–sumes rotation of the north direction into a real position. Once distinguished and defined the "project north" and "true north" require swit–ching between the two modes when necessary, but ensure a precise simulation of the sun position, and therefore accurate shadow represen–tations and other solar analyses.

3.4 Visualising position of Sun

Once having completed the geo-location of a virtual building, and oriented it properly, it makes sense visu–alising position of sun, i.e. turning on the sun-path. The position of sun is represented by a celestial sphere, more precisely by its part determined by the two characteristic diurnal circles – the ones representing the solstice days, as well as by its great circle representing the horizon on which it is possible to read the azimuth angle. It is important to stress that the celestial sphere is created for one particular point and this point is the starting point of the model (point 0,0,0). The accurate sun ray for a given date and time connects the sun (represented by a little sphere) positioned on an appropriate diurnal circle, and the starting point of the model. The representation of sun is often an interactive object that could be moved along the diurnal circle (changing the time of the day) or along the analemma diagram (changing the date of the year but keeping the same hour of the day). It might be useful to understand that the spherical sun representation is not a vector object the centre of which could be connected with other points of model. That is because it represents the sun position for a unique point and could not be used for simulating sun rays cast on other points of the model.

3.5 Casting shadows

If the building site properly selected and orientation pre–cisely defined, the BIM software allows easy and accurate simulation of shadows cast on a selected day and time (Fig. 17, left). Some programs offer a possibility to examine shadows on predefined characteristic days, i.e. equinoxes (which give a sort of average shadow) and solstices (which give extreme summer and winter shadows).

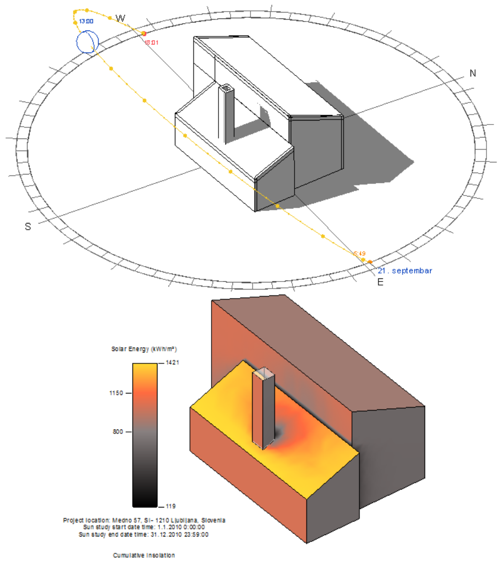

Figure 17. An example of the solar study(left) for a house in Ljubljana, Slovenia (LAT 46.12°, LON 14.44), on the fall equinox afternoon, and the annual irradiance study (right) with a visible overshadowing effect from the chimney

From the viewpoint of designing solar systems it is important to understand that the shadow of a geometry resulted from the sun light is dynamic, so it needs to be observed in selected time frames and statistically examined.

3.6 Solar analyses

There's a variety of solar analyses that could be per–formed within available BIM software, ranging from simple animations showing transformations of shadows during a selected time frame, to sophisticated daylight interior visualisations and measurements. The most re–levant for designing of photovoltaic systems is the analysis of the solar irradiance, including the representation of overshadowing by exposed elements of building geometry (Fig. 17, right). The irradiance calculation in the Revit software is based on the Perrez model [33] that particularly defines the diffuse part of received irradiance.

4. CONCLUSION

A variety of BIM software is available nowadays, supporting architectural design with numerous sophisti–cated tools, including the ones allowing different solar analyses and even estimating solar potential of designed buildings. For an efficient using of such tools it is useful and sometimes necessary to understand the geometric concepts behind. Starting from the basic sun-earth geo–metry, through the explanations of determining the Sun's position on particular location and calculations of the Sun ray incidence angles for a tilted surface (possible PV mo–dule), this paper reviews the most important elements of the geometric apparatus that during the last decade has become a standard functionality of typical BIM software. The paper considers the main references on solar geo-metry dedicated to architectural designers published from the 80s onwards, and acquires the nomenclature proposed by Szokolay as more suitable for architects. It is aimed atthe contents that should be considered in teaching archi-tecture students in the process of introducing BIM based solar studies, as well as a start point for architects inten-ding to integrate PV systems in their future designs.

This study is a starting point for a future research, which can lead towards an optimisation of solar systems on particular locations, in terms of their geometric modelling using BIM tools. In the focus of the planned research would be a geometric design of adaptive building integrated PV modules.

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ПРОЈЕКТОВАЊЕ СОЛАРНИХ СИСТЕМА ЗА АРХИТЕКТОНСКЕ ОБЈЕКТЕ И BIM АЛАТИ: ПРЕГЛЕД РЕЛЕВАНТНИХ ГЕОМЕТРИЈСКИХ АСПЕКАТА

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У раду су систематизовани најважнији геометријски аспекти који су релевантни за целовито разумевање пројектовања фотонапонских система. Ова систематизација се базира на прегледу литературе намењене различитим инжењерима, укључујући архитекте који су укључени у мултидисциплинарне процесе концептуализације, пројектовања и реализације фотонапонских система. Разумевање приказаних геометријских аспеката, у литератури обједињених под називом соларна геометрија, значајно је не само због проналажења оптималне оријентације и најефектнијег нагиба фотонапонских модула, него и због адекватног обликовања геометријски комплексних фасадних елемената, који би требало да буду оптимално осунчани током целе године.

Након детаљног објашњења основних елемената соларне геометрије коришћењем сферне тригоно–метрије, у раду је продискутована интеграција приказаних геометријских концепата у BIM окружења, илустрована примером модула за анализе осунчања у оквиру софтвера Revit, фирме Autodesk. Анализирана је функционалност свих интерактивних компонената 3Д приказа сунчеве путање. Наглашена је потреба за експлицитнијим одређивањем упадног угла сунчевих зрака на нагнуту површ фотонапонског модула.

У закључном делу издвојено је оно знање о соларној геометрији које би било неопходно усвојити у процесу архитектонског образовања, како би пројектанти који раде у BIM окружењу били припремљени за ефикасну концептуализацију интегрисаних фотонапонских система.