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Environmental impact assessment of *Pinaceae* airborne pollen and green infrastructure using BIM

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ABSTRACT

Urban air quality is a parameter that plays a major role in human health at the local scale. Consequently, in urban planning, the behavior and potential risk of allergenicity for some pollen grains coming from ornamental trees and green spaces surrounding newly built buildings, should be considered. This paper aims to study how pollen exposure, influenced by weather parameters, can be assessed and integrated in the designing and building of constructions as other component of air quality assessment beforehand, by using BIM. Based on a comparative aerobiological study at the height over a building (sampled by two traps at ground and at 16 m), a 3D local dynamic parametric scenario was modelled using BIM, and hourly average *Pinaceae* pollen concentrations (due to the closeness of pine trees to the samplers). From continuous recording (2009–2011) influenced by height and the influence of wind direction and speed was analysed. Additionally, a map of pine trees geolocated around the studied building was produced and the hourly average *Pinaceae* pollen concentrations were represented by Revit. BIM together with aerobiology can be a novel and useful tool for the construction of buildings considering airborne biological particles. This represents a first step towards the integration of some unusual environmental parameters in urban planning. Pollen grains modelling as an environmental health criterion for the construction of new buildings will allow technicians to avoid possible future isolation points in the design of building envelopes, and high pollen exposure rates could be avoided, creating 'allergy-free' buildings.

1. Introduction

Building information modelling (BIM)-based technologies and lean-based methods (construction and environmentally lean and efficient production) have been applied to environmental, social and economic concerns. This approach has contributed to the construction industry, playing a proactive role in the development of new sustainable services and manufacturing processes [1] and leveraging synergies between green aspects (environmental analysis, environmental science and sustainable development) and BIM and lean construction. Caiado et al. [2] indicated the need to consider social aspects coupled with the use of tools and techniques to advance sustainable development. Novel sustainability environmental indicators and pollution, such as life cycle CO_2 emissions (LCCE) [3] or low-carbon building measure selection [4] in green buildings [5], have been assessed by BIM. Additionally, various indicators used to assess environmental impact, such as the greenhouse gas (GHG) footprint, eutrophication potential (EP), acidification potential (AP), human health (HH) particulate, ozone depletion and smog, may be included [6,7]. BIM has evolved from 3D to computable nD through different industrial and urban code guidelines [8] that may be applied in urban planning and design [9]. BIM is a 3D digital data space for sharing building information that enables multi-disciplinary collaboration among various actors involved in the life cycle of buildings [10]. This technology allows the generation of a virtual prototype of the building to which a database is associated, as is proposed in this article with aerobiological data as part of air quality assessment. BIM models contain information beyond only geometry in terms of parametric data that can be manipulated in various analyses, quantity take-offs, detailed documentation, etc. [10]. BIM software defines these objects parametrically so that if a related object is amended, dependent ones will also change automatically [11]. To generate the BIM models, Autodesk Revit is often used since it is one of the more well-known BIM authoring tools used for 3D modelling of complex development in the AEC industry [12].
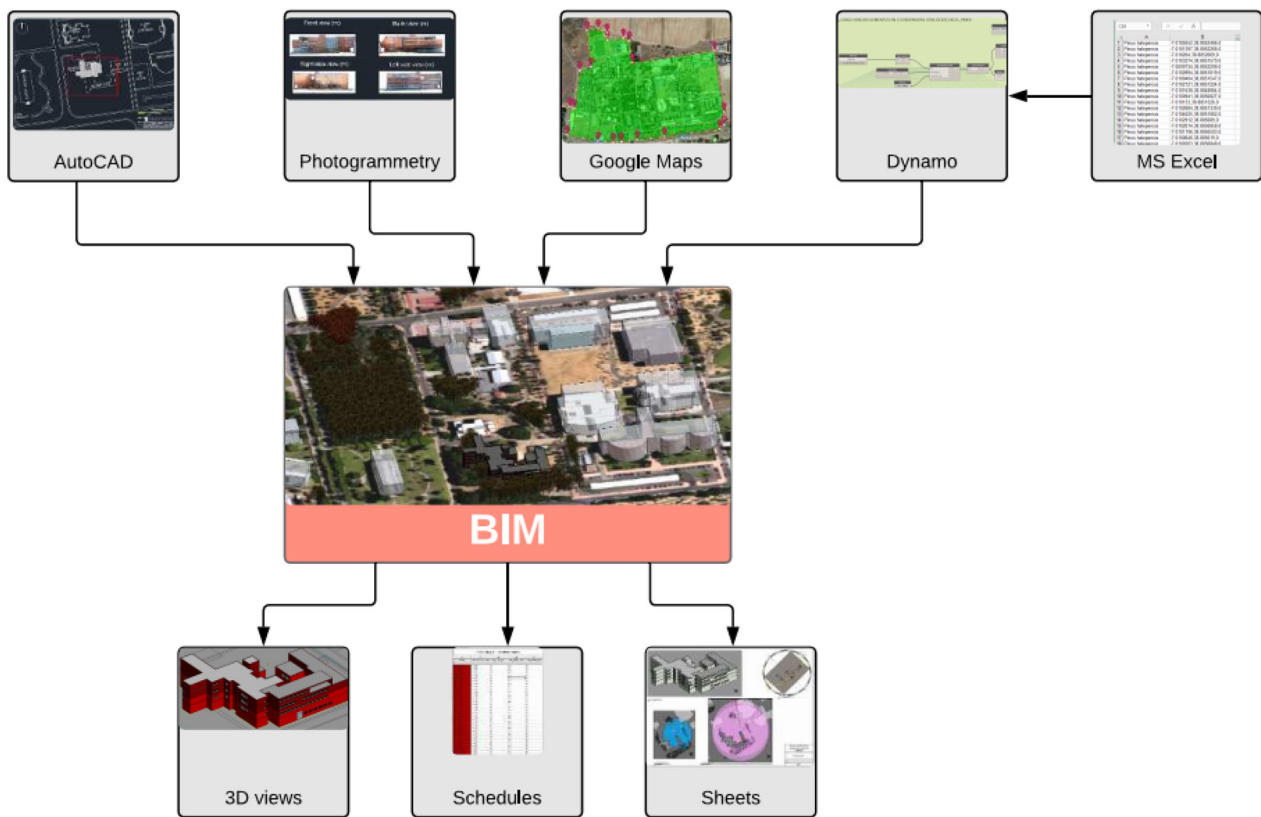
Fig. 1. BIM work scheme.

Integrating 4D in the evaluation of elevated urban projects is interesting for the simulation of phasing evaluation and decision makers [13]. So, the integration of 4D BIM models has been already applied to indoor air quality [14]. Urban planning has been studied from several points of view: empiric design evaluation [15], climate change in urban areas [16], environment and energy geographic information System (E-GIS) [17], distribution of buildings in urban green space [18], urban sustainability management [19], infrastructure ecology as urban development [20] and green area management in urban ecological sustainability [21]. Consequently, the urban landscape is of great interest, and other studies have linked population and visual preferences for vegetated green space [22] and the effects of aesthetic quality [23]. A better understanding of the role of the urban environment [24] and ecosystem services is needed for making decisions [25] that impact socioeconomic factors [26] for assessing and evaluating sustainability comparisons of green infrastructure interventions [27]. Together with the benefits of urban green infrastructures relating to thermal aspects and land use [28,29], much attention has recently been paid to the origin of natural urban sources of pollution originating from ornamental trees, shrubs and herbs [30] due to human interactions in urban green spaces [31].

As a consequence of the construction process, habitat fragmentation occurs, which has effects on spatial patterning, particularly those creating obstacles to the dispersion of organisms and materials (nutrients, sediment or pollen) [32]. The importance of local scale in the assessment, monitoring and prediction of urban air quality has been highlighted [33] through the effect of urban canyons [34] or their influence on the heat island potential [34] and on thermal comfort afforded by trees [35]. Papers have studied the impacts of trees on particulate matter ($PM_{2.5}$) dispersion in urban streets [36,37] and microclimate and air quality in urban areas [38]. Another new parameter considered in urban impact assessment is aerobiology, which concerns the release of aerobiological particles, mainly pollen grains and fungal spores in the air, as well as bacteria, viruses or other

bioaerosols. However, the most important aerobiological particles are pollen grains coming from trees such as *Cupressaceae* [39], *Olea* [40], *Quercus* [41] or from herbs as *Poaceae* [42,43].

Environmental impact assessment is linked with aerobiology through the changing climate [44]; modelling of environmental systems [42]; life cycle analysis and sustainability assessment [45]; characterization, management and treatment of atmospheric pollution [46]; and urban metabolism and ecological urbanism [47]. According to the main steps of environmental impact assessment protocols, the aerobiology fields are included as indicators (mainly pollen grains and fungal spores) of public works to be subsequently applied in the environmental inventory; preventive, corrective and compensatory measures; and environmental monitoring programmes [48,49]. Taking research and policy as tools to address the impacts of future risks provoked by pollutants should be considered as a mean to avoid exposure in future urban construction.

Based on a comparative aerobiological study over a building in a city in the SW Iberian Peninsula [50], *Pinaceae* pollen was one of the five main pollen types found, showing statistically significant differences in altitude, indicating that height influences the distribution of this pollen type. Moreover, the pine trees were close to the samplers, and the pollen had a limited capacity to float due to the large size of the grains ($> 50\,\mu m$). *Pinaceae* pollen has been recorded at various distances; *Pinus hallii* is well represented locally, but its pollen is rarely recorded $> 50\,m$ from the parent trees. Long-distance transport of pollen occurs at a low frequency [51], and *Pinus roxburghii* pollen frequency declines rapidly as the distance from the source increases, with the highest densities $< 100\,m$ from the source [52]. In fact, Fernández-Rodríguez et al. [50] showed that *Pinaceae* was the only pollen type that showed a significant correlation between daily concentration at two heights with wind direction and speed. Direct exposure to the sun has been shown to be a significant parameter for both herbs and trees [53–56]. On the other hand, *Pinaceae* pollen has been considered in studies investigating ambient pollen concentrations and allergic

problems [57–59] and has been shown to have a low prevalence of allergic sensitization [60]. All these features make this pollen type suitable to study over buildings with two samplers to analyse the influence of ornamental trees as local sources pollen grains. The use of new models of representation, such as BIM, is appropriate (Fig. 1).

The aim of this paper was to study how pollen exposure, taking into account weather parameters, can be assessed and integrated in the designing and building of constructions as other component of air quality assessment beforehand, by using BIM as tool. We propose BIM as a powerful tool to consider aerobiology as other component in air quality analysis, being this technic capable to model, simulate, analyse and visualize urban environments by combining parametric modelling with agent-based simulation.

2. Materials and methods

2.1. Sampling site and pollen data

The study was conducted in Badajoz, a city in the Extremadura region (SW Spain), from two sampling points at nearly the same place near the biology building (38°88′28″N, 7°00′85″W) of the Faculty of Science, Badajoz Campus (University of Extremadura, Fig. 2), but at different heights (Fig. 3: one at ground level in the experimental garden (g) and the other at 16 m high in the terrace (t), separated by a 20-m horizontal distance. A 7-day volumetric sampler was used to record pollen [61]. According to previously published papers by Tormo-Molina et al. [62] and Maya-Manzano et al. [63], the adhesive petrolatum white (CAS number 8009-03-8) was used to capture airborne pollen. Standardized data procedures were followed as indicated by the Spanish Aerobiology Network (REA; [64]). The daily average (0000–2400 h) pollen counts and the intradiurnal variations-coordinated universal time (UTC) hourly counts were expressed as pollen grains/m³ of air.

Pinaceae pollen was studied over 3 years (2009–2011), the main pollen season (MPS) being estimated using the 5–95% range method [65]. According to this criterion, the pollen season starts on the date when the sum of pollen grains from the beginning of the year reaches or exceeds 5% of the total annual pollen concentration and ends when the

95% of this total is reached or exceeded. To select episodes, the maximum hourly peaks were analysed. For the analysis of the intradiurnal pollen pattern, five continuous days (120 h) were selected that included the day with the peak pollen level in each year. These five days were selected depending on the pollen type at the ground (50.6%) and terrace (52.1%) levels.

2.2. Meteorological data

Various meteorological parameters were provided by the AT Delta-T DL2 fixed weather station situated at the experimental garden of the biology building on the Faculty of Sciences campus. This station is located 3 and 20 m from the garden and terrace samplers, respectively. The meteorological parameters considered in this study were wind direction (Wd), wind speed (Ws), sun hours (Sh), relative humidity (Rh), rainfall (R), solar radiation (Sr) and mean air temperature (Tmean).

2.3. BIM technology applied to the management of pollen on buildings

The use of BIM technology allowed the centralization of different types of information from different sources, such as geographic coordinates of trees, data in 2D CAD planes and data about pollen concentration, in a single 3D model to study and represent the pollen concentration in the envelope of the study building. First, the topography of the area was obtained through the Revit plugin that links data with Google Earth, called CADtoEarth. Then, modelling of the building and of its location in the environment was carried out. With the aim of creating a virtual prototype of the building, we started with the information contained in the 2D CAD plans, with the on-site representation of the buildings that make up the Badajoz campus provided by the University of Extremadura. From these plans, we obtained the dimensions, orientation and relative positioning of the buildings (Fig. 2). To obtain information on the elevation, dimensions, and location of the windows and doors, photogrammetry was used to obtain 2D elevations (Fig. 3). From this information, modelling of the building was carried out at its real location (Fig. 4). The model building consisted of the exterior volume, including the windows and doors of the facades. Each of the facades was modelled in sections that correspond to
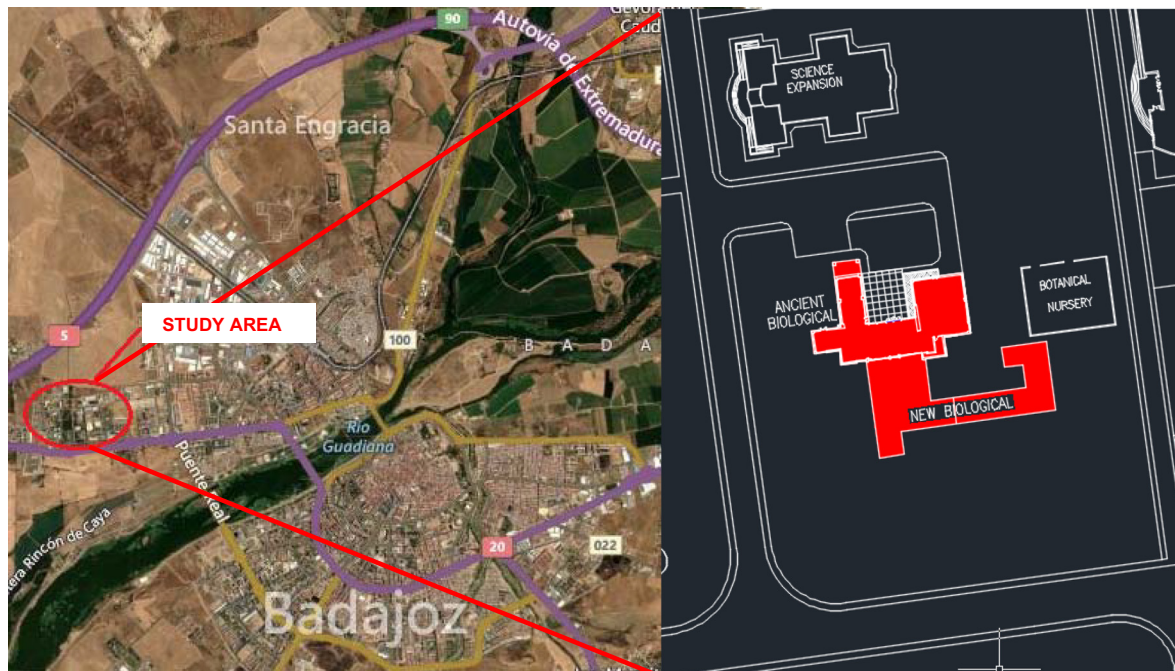

Fig. 2. Defined area of the Badajoz Campus belonging to the University of Extremadura.

Fig. 3. 2D elevations of the building. Photogrammetry.

the heights of the floors of the building. To show the influence of height on pollen concentration, a pollen concentration parameter was created in the facade elements, these being the elements most exposed to pollen. Once the building in Revit had been modelled and located, each tree was placed in its exact position. The placement in the model of the 557 *Pinus* spp. included in the study was done using their UTM coordinates. For this, the Revit plugin (DYNAMO) was used (Fig. 5). The Autodesk Revit API (Application Programming Interface) enables users to add features to the software [66] and automate tasks through visual programming codes. Dynamo is a visual programming environment that extends the parametric modelling capabilities of Revit by adding a level of associativity that does not exist in the standard application [66]. The arrangement of these features is fundamental for the analysis of the effect of pollen on the study building, considering variables such as wind direction, temperature with respect to height and possible interference with the environment. This approach made it possible to introduce unrelated information coming from different sources in a single model, in turn allowing us to integrate and interrelate elements of interest, which were the building and the trees in their corresponding locations, in the study (Fig. 6).

According to Fernández-Rodríguez et al. [50], there is a significant influence of the height of the samplers on the daily concentration of pollen grains. Revit allows the user to define parameters and their 3D representation. To analyse the spatial variation in pollen, a parameter called "*Pinaceae pollen concentration*" was generated in the Revit model. To analyse this spatial variation in relation to the rest of the factors that influence the concentration, a 3D representation of the model and the

environment was obtained, forming a single file with an associated database. In this study, the walls that make up the envelope defined a series of parameters that allowed the introduction of values corresponding to the pollen concentrations at variable heights. These pollen concentrations were obtained from a linear interpolation between the pollen concentration values from the samplers located in the terrace and in the garden. After data entry, visualization filters were generated to represent the concentration of pollen in each of the sections of the building based on the study variables. To do this, chromatic scales were defined that indicate the variation in the pollen concentration by height. 3D figures of the complete model were obtained, including the representation of the nearest *Pinus* spp. [51,52], which produced radii of action at 50, 100 and 150 m that directly affected the *Pinaceae* pollen that reached the building envelope.

3. Results

3.1. Urban map of pines trees

A total of 557 pine trees were counted, namely, 445 *Pinus pinea* and 112 *Pinus halepensis*, in a total of 0.53 km^2, which corresponds to the entire area of the campus. Considering each of the samplers (garden and terrace) as a centre, action radii were established at distances of 50, 100 and 150 m to obtain the number of trees regardless of their species that were contained and therefore able to influence the pollen concentration at the samplers. Fig. 7a–c shows the geolocation of pine trees around each sampler and each radius of action near the biology building of the

Fig. 4. BIM model of the building.

Fig. 5. Dynamo code to locate elements by coordinates.
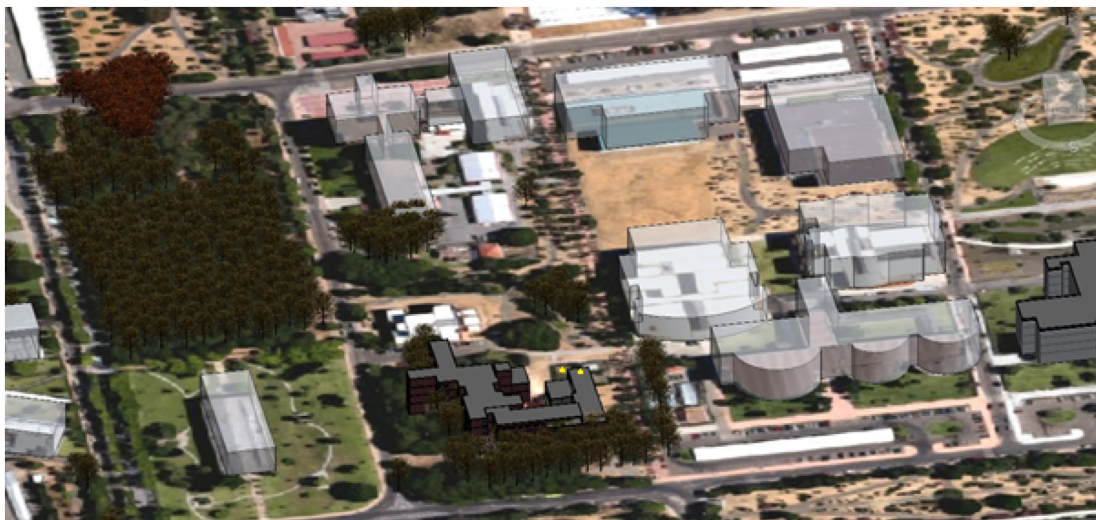
Fig. 6. Location of pollen traps including *Pinus* spp. and the meteorological station.

Badajoz Campus of the University of Extremadura.

3.2. Hourly analysis of episodes

Based on a previous study by Fernández-Rodríguez et al. [50], the hourly average *Pinaceae* concentration from 2009 to 2011 at 0800,

1400 and 2000 h using Revit (Fig. 8) was recorded. The selected episodes for the maximum daily *Pinaceae* pollen included 3 annual periods with a total of 15 days; 22nd–26th April 2009, 28th April–2nd May 2010 and 16–20th April 2011 (Fig. 8). Table 1 shows the hourly concentration and meteorological comparison by height. We found a highly statistically significant positive correlation for *Pinaceae* concentration

(a)

(b)

(c)
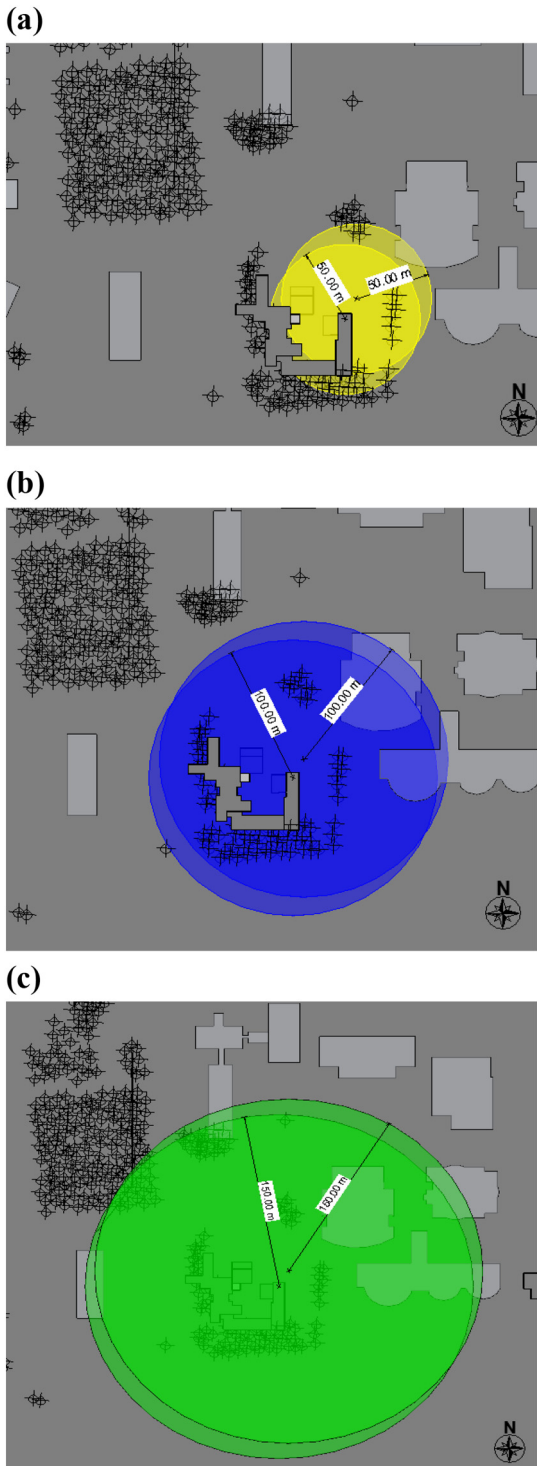
Fig. 7. Pines trees geolocated at the campus of the University of Extremadura in Badajoz at 50 m (a), 100 m (b) and 150 m (c) from the samplers at ground and terrace levels at the biology building.

in all episodes. However, the maximum peaks did not occur on the same day in all cases. Hourly peaks occurred, on average, between 13 and 16 h in most cases, although peaks could appear at nearly any hour of the day, including night hours. Peaks occurred on average first at 16 m on the terrace and 2.5 h later at ground level. Two similar hourly peaks on the same day appeared in some cases but on only 2 out of the 15 days studied. Likewise, an advance of 0.69 h (41.4 min) for the terrace and 0.76 h (45.6 min) for the ground was found when the maximum

concentrations were compared with the highest wind speed during this interval. It could be due to that for pollen releasing, to reach the gust of wind is not needed, and previous rises on wind speed are enough to allow this release. Hourly mean temperature and solar radiation showed a statistically significant positive correlation with hourly peaks, and relative humidity showed a negative correlation. Speed and wind direction showed different significant correlations depending on the episode. Fig. 9 represents the intradiurnal *Pinaceae* pollen levels, together with the main directions which increased *Pinaceae* concentrations and frequency for wind speed and direction. The main wind direction in the 2010 and 2011 episodes was between 125° and 175°, whereas it was between 150° and 200° on the study days in 2009. The maximum values of wind speed were the same in the 2010 episode. Fig. 10 shows a 3D representation of the urban map with pines trees around the biology building and the speed and direction wind for selected three hourly cases on 29 April 2010. In this particular case, the *Pinaceae* concentration changed in 3 h (12–14 h): from 3140 grains/m^3 (12 h) with a wind speed of 0.36 m/s and the wind direction blowing from 122° (SE), to 3866 grains/m^3 (13 h) with 0.61 m/s and 106° (E-SE), and finally 1868 grains/m^3 at 14 h with a wind speed of 1.19 m/s and a wind direction of 213° (SW).

4. Discussion

Despite the fact that there is now international awareness of the regulation of urban green spaces, studies on the design of green areas [67] do not include aerobiological information or the interaction of tree species in these spaces with the surrounding buildings [18,68]. Our results may serve to advance the incorporation of aerobiological information as an element of the design of green infrastructures, potentially avoiding the entrance of pollen on them. In this case, pines trees in BIM models of green areas and modelling of buildings in their environment. The methodology followed in this study is based on the scheme proposed by Aschwanden et al. [15]. This work developed a 3D model based on contour lines as masses in Zurich (Switzerland). This model considered geographical parameters (topography, elevation, obstacles, land use and skyline) to investigate topics such as accessibility of amenities, quality of services and pedestrian comfort. In the same way, in the present study, we modelled part of Badajoz Campus (Spain) using information from environmental topography maps, the species to be investigated and their geolocation, the contour of the buildings as masses and various circulation zones. However, more urban aspects linked to air quality components and infrastructures could be considered using the results shown in our maps, including the proximity of ornamental fountains to citizens, healthy itineraries and building access areas, including the main windows exposed to allergenic risk. The study focused on the interaction of pollen with walks and buildings, analysing the 3D diffusion through the representation of the concentration of pollen on the envelope of the building closest to the samplers. This building was also modelled in greater detail using photogrammetry performed on its entire perimeter, which allowed us to precisely define the external volume and envelope, including the windows and doors [69], which are important for the quality of the indoor environment of the building [70]. According to green areas management practices, planting trees to improve local air quality has been considered [21]. This paper indicated that a major challenge to this is finding the best solution for a peculiar natural context in which an intervention is required.

To analyse the variation in pollen concentration, we used a previously described methodology [14], where the outdoor dust concentration was analysed using BIM and the effects inside the building were considered together with the number of sources in the same way that in our study. In our study, pollen dispersion was considered according to the number of producing elements (trees) through the creation of circles of different radii that included an increasing number of pollen-generating trees with increasing area. A previous study

Pinaceae pollen concentration 60-100 grains/m³

Pinaceae pollen concentration 101-140 grains/m³

Pinaceae pollen concentration 141-180 grains/m³

Pinaceae pollen concentration 181-220 grains/m³

Pinaceae pollen concentration 221-260 grains/m³

Pinaceae pollen concentration 261-300 grains/m³

Pinaceae pollen concentration 301-340 grains/m³
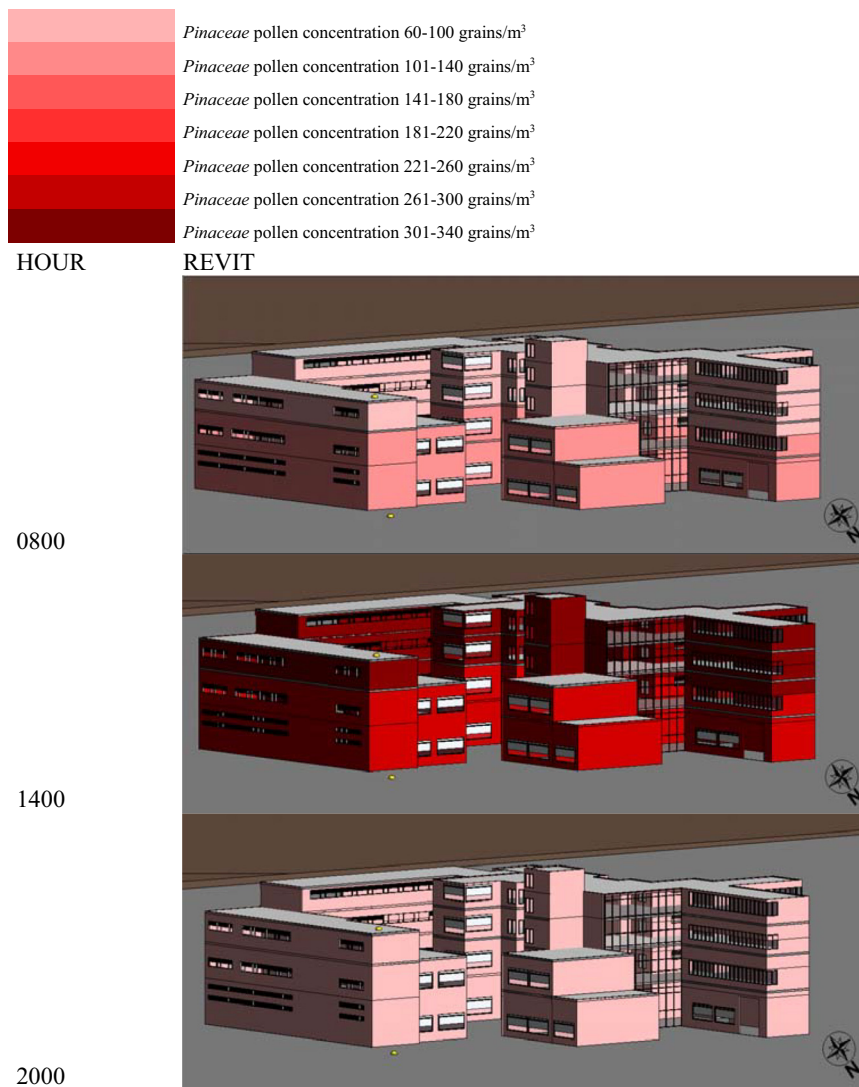
Fig. 8. Hourly (0800, 1400 and 2000 h) average *Pinaceae* concentrations from 2009 to 2011.

Table 1

Spearman's correlation test comparing the hourly *Pinaceae* pollen concentration in the terrace level at 16 m (t) and at ground level (g) during the selected test periods (22–26 April 2009, 28 April to 2 May 2010 and 16–20 April 2011).

2009	Statist	t	g	Rain	Tmed	Ws	Wd	RH	Rad
t	r		0,729**	.	0,323**	0,383**	0,101	−0,325**	0,443**
	p		0,000	.	0,000	0,000	0,274	0,000	0,000
g	r	0,729**		.	0,380**	0,550**	0,123	−0,383**	0,364**
	p	0,000		.	0,000	0,000	0,181	0,000	0,000
2010	Statist	t	g	Rain	Tmed	Ws	Wd	RH	Rad
t	r		0,940**	.	0,261**	0,612**	0,089	−0,364**	0,518**
	p		0,000	.	0,004	0,000	0,335	0,000	0,000
g	r	0,940**		.	0,277**	0,674**	0,152	−0,391**	0,508**
	p	0,000		.	0,002	0,000	0,097	0,000	0,000
2011	Statist	t	g	Rain	Tmed	Ws	Wd	RH	Rad
t	r		0,842**	−0,049	0,327**	0,165	−0,103	−0,265**	0,154
	p		0,000	0,596	0,000	0,072	0,265	0,003	0,092
g	r	0,842**		−0,054	0,284**	0,209*	−0,233*	−0,206*	0,173
	p	0,000		0,560	0,002	0,022	0,010	0,024	0,058

** Correlation; significant at 0.01 level (bilateral).

* Correlation; significant at 0.05 level (bilateral).

(a)

(b)

Hourly average pollen concentrations sums (pollen grains m⁻³) and Wd 2009

(c)

(d)

(e)

Hourly average pollen concentrations sums (pollen grains m⁻³) and Wd 2010

(f)

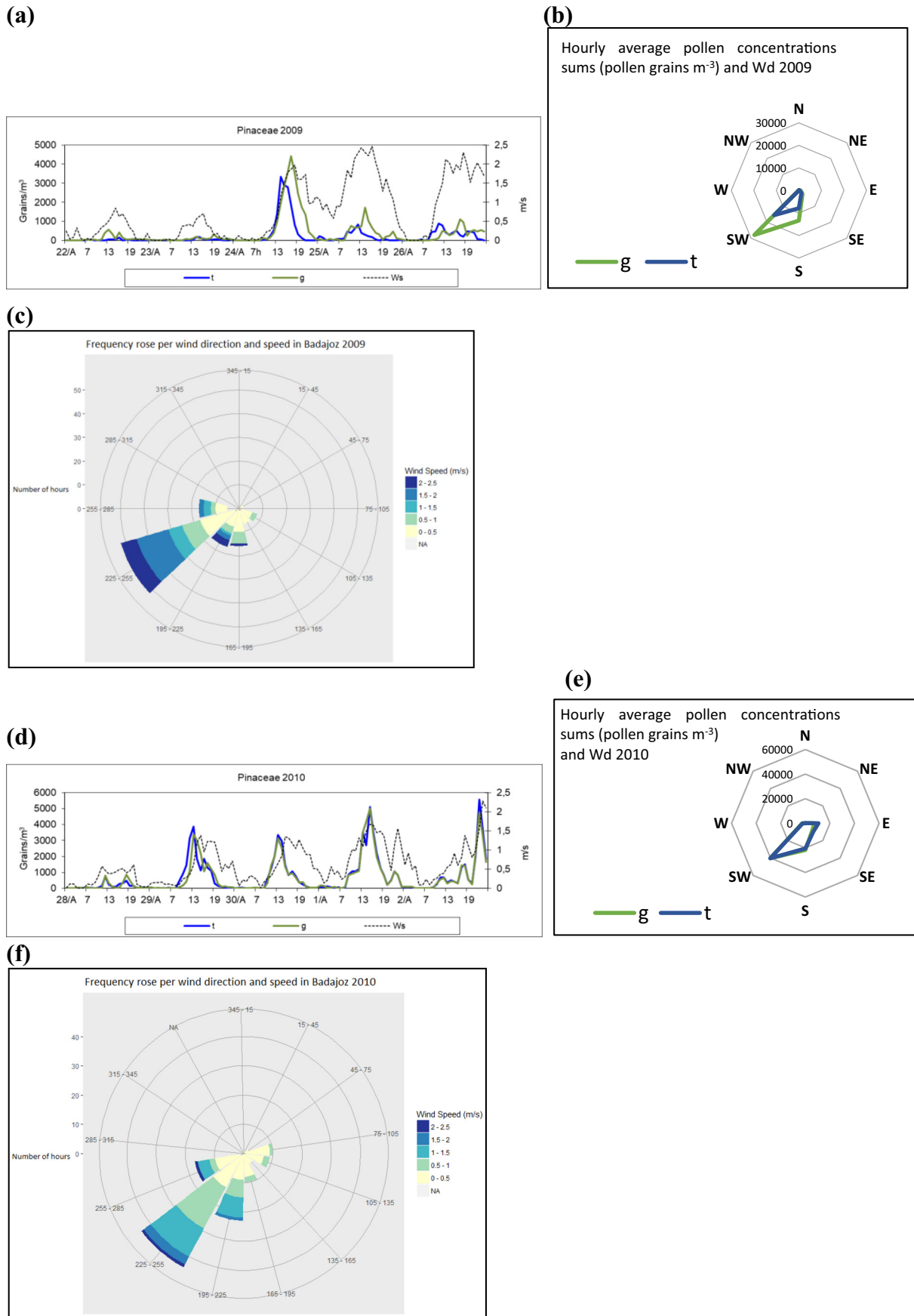**Fig. 9.** Intradiurnal *Pinaceae* pollen concentrations at 16 m (t) and at ground level (g) with wind speed (Ws) and direction (Wd).
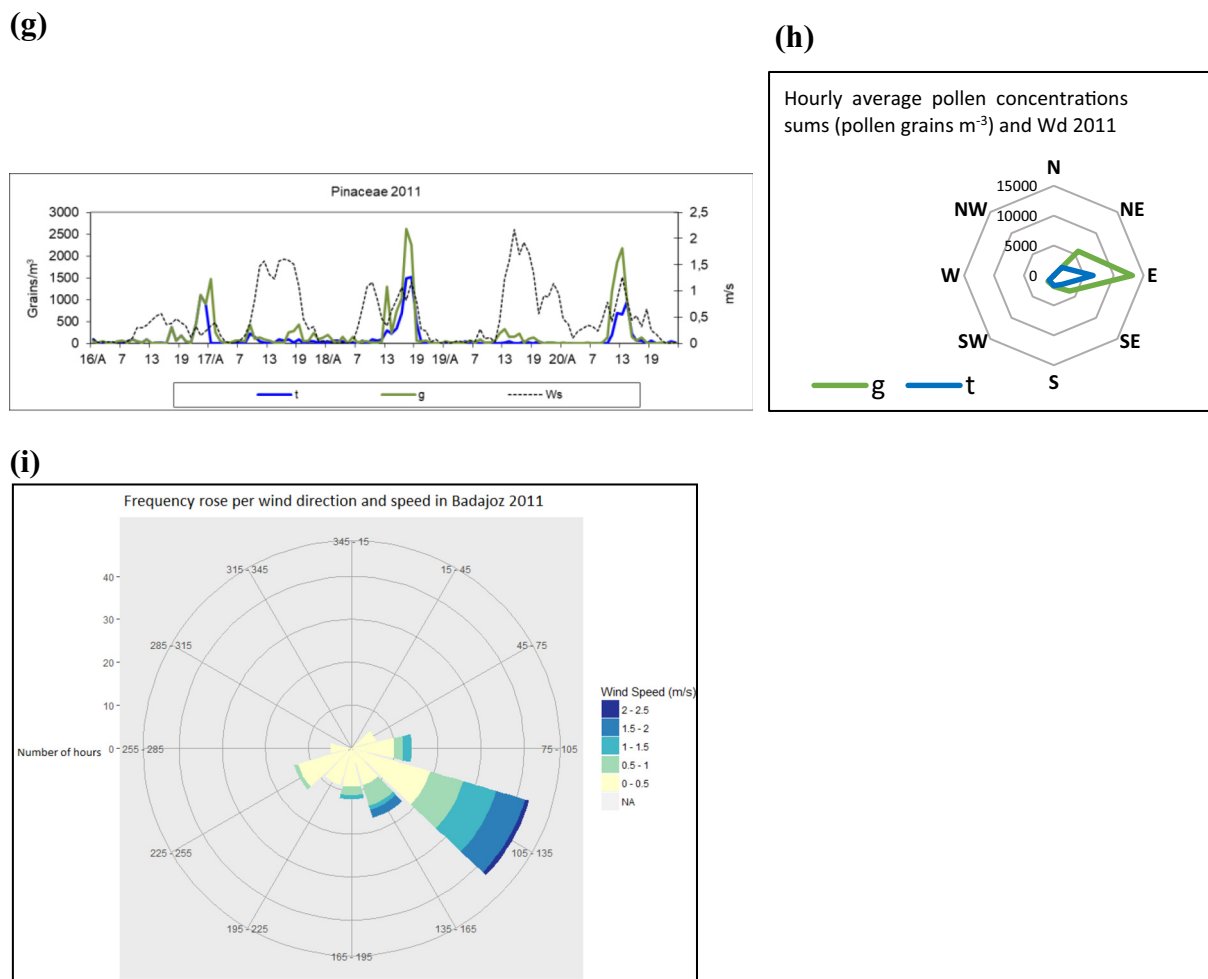
(g)

(h)

(i)

Fig. 9. (*continued*)

calculated the pollen production from other Mediterranean pines species (*Pinus pinaster*) per meter of tree crown, that could be comparable with the species here considered, obtaining values ranged 3–5·10⁹ pollen grains per meter of tree crown diameter [71]. Altaf et al. [14] introduced ventilation as an important factor within the BIM model. In this study, wind direction, which was demonstrated to be correlated with pollen concentration, was included in the model. The wind direction pattern within a city is an important parameter to be consider because it affects measurement of the pollen concentration coming from those sources located in the path of the main wind direction to the pollen trap and can lead to overestimation [63,72]. Consequently, modelling carried out using BIM has shown to be a powerful tool to interpret these spatial variations at a very local scale of a few dozen of metres. This knowledge provides an opportunity to understand the pollen gradient because thus far, there has been a gap in aerobiology concerning this scale, and only a few articles have analysed height pollen gradients [73].

The 3D visualization of the hourly average concentration *Pinaceae* pollen is shown in Fig. 8. This result can be included within smart green city development, specifically in terms of health. Similar results have been obtained by the Korean government [74], where an application was developed to visualize temperature, humidity and CO_2 in 3D. Data about the proximity of ornamental sources to building doors can help to determine areas with a higher risk of high pollen levels, providing a new parameter for environmental and allergological assessment. Analysing these data could help to manage building access through green spaces, assuming advances from other accessibility studies [75]. In this previous study, the authors established an automatic building

accessibility diagnosis from point clouds in four real case studies in Vigo using a methodology with straight streets of approximately 150 m, with trees on sidewalks and building entrances to shops and dwellings. An effect of altitude over the facades of buildings was observed. Our study showed similar results with other parameters, including hourly average *Pinaceae* concentration (Fig. 9) and hourly wind direction and speed (Fig. 10). Balado et al. [75] only addressed the point of view of physical disabilities, whereas our proposal identifies areas with higher concentrations of pollen, which is fundamental information for the management of accessibility to spaces for people with allergies.

Currently, there are various proposals for BIM dimensions that extend from 3D to 6D or 7D [8,76]. In these studies, BIM dimension proposals are associated with aspects intrinsic to the building and its construction, such as execution time, cost and maintenance. The results presented in this study allow us to approach a new dimension for the BIM in which the building is placed in context with its environment, in this case, airborne pollen. This approach opens a new dimension in BIM modelling, allowing the introduction of allergenic species that are important for aerobiological purposes as new criteria in the design of buildings using BIM methodology. From this perspective, green building research focusing on ventilation is an interesting field of study [77].

As in a previous study of ornamental pollen types from cities in the SW Iberian Peninsula, *Pinaceae* pollen was important based on the concentration and number of ornamental trees [47]. In that study of cities in Extremadura with a smaller population and a lower density of pine trees per hectare, 577 *Pinaceae* trees in Don Benito, 295 pine trees in Plasencia and 207 in Zafra were counted. Its abundance is justified
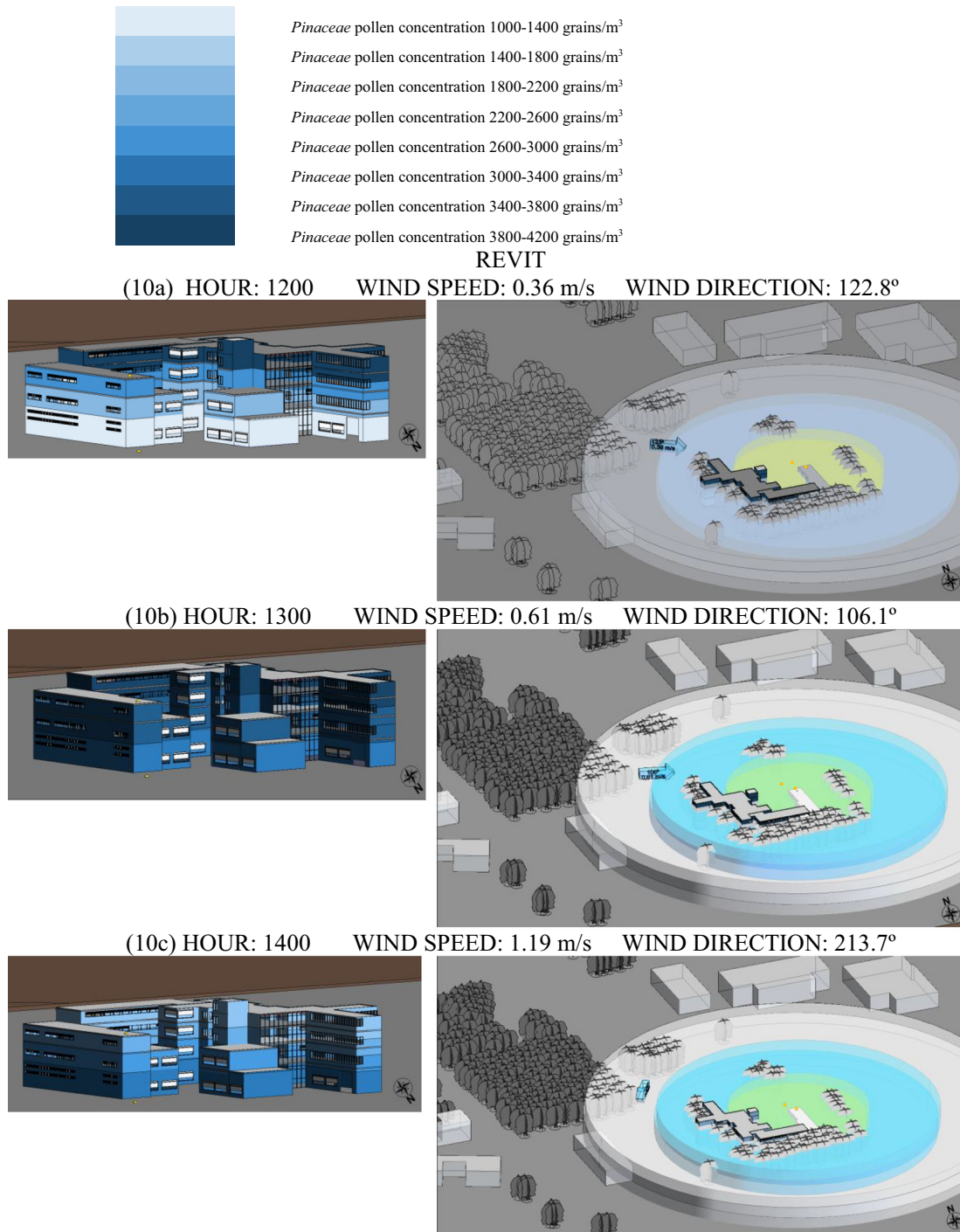
Pinaceae pollen concentration 1000-1400 grains/m^3
Pinaceae pollen concentration 1400-1800 grains/m^3
Pinaceae pollen concentration 1800-2200 grains/m^3
Pinaceae pollen concentration 2200-2600 grains/m^3
Pinaceae pollen concentration 2600-3000 grains/m^3
Pinaceae pollen concentration 3000-3400 grains/m^3
Pinaceae pollen concentration 3400-3800 grains/m^3
Pinaceae pollen concentration 3800-4200 grains/m^3

REVIT

(10a) HOUR: 1200   WIND SPEED: 0.36 m/s   WIND DIRECTION: 122.8º

(10b) HOUR: 1300   WIND SPEED: 0.61 m/s   WIND DIRECTION: 106.1º

(10c) HOUR: 1400   WIND SPEED: 1.19 m/s   WIND DIRECTION: 213.7º

Fig. 10. 3D representation of an urban map with pine trees around the biology building and the wind speed and direction for three selected hourly cases on 29 April 2010.

due to the role played by Pine trees, which provide ecosystem services in urban plans, including urban temperature regulation, air purification and recreation [25]. Pine trees can be considered for use in garden cities and eco-urbanism [78]. The size of the urban area we studied was similar to that of previous studies [33,79,80]. Our study can serve to highlight the importance of considering ornamental flora at the local scale for assessing, monitoring and predicting air quality in urban areas [33,81].

The intradiurnal variation in *Pinaceae* pollen during the selected episodes showed a similar hourly pattern with two peaks, one maximum at midday and another at the end of the evening. Similar results

were found in previous studies of the annual main pollen season of *Pinacae* pollen in Mediterranean countries such as Portugal [82], Spain [50] and Turkey [83]. Peaks occurred on average first at the terrace and 2.5 h later at ground level. On the same day, 2 similar hourly peaks appeared in some cases (15 days). Kong et al. [35] investigated the effect of wind flow on a street canyon with trees. The flow of air passes the building and passes through the crown of the tree by convention. In this process, the air can be associated with pollen particles from the tree. The coincidence of these results with hourly data, including the maximum concentrations, highlights the importance of using hourly data in considering new urban environmental planning scenarios.

The relationship of *Pinaceae* pollen concentration and hourly meteorological data showed a positive statistically significant correlation with mean temperature and a negative statistically significant correlation with relative humidity. However, there was no rainfall during the 2009 and 2010 testing periods, but rain did occur in 2011, when a negative correlation was found. These results are in line with those of previous studies [82,83]. In our study, a positive effect of wind speed for all episodes is consistent with the results of Ribeiro et al. [82] but disagrees with the results obtained by Uguz et al. [83]. This fact might be related to the distance (0.6 km) from the meteorological station to the pollen trap, in contrast with our case, where both stations were closer. Furthermore, a map of ornamental trees was not supplied, so the analysis of the proximity of the ornamental sources and the wind speed could not be performed. Damialis et al. [84] indicated that the absence of a relationship between wind components and pollen counts for *Cupressaceae* might be explained by the fact that this plant taxon has a high local distribution. Although sources were more abundant in the SW and W, from where the wind predominantly blew, the wind direction did not show a statistically significant correlation with *Pinaceae* pollen. It can be due to the nearness of the sources to the pollen traps, with the possibility that refloating processes increasing the concentrations outside the main pollen season, especially with gardening work that was being done during the day in the campus. Also the presence of buildings with different materials (which suffer different levels of insolation, saving heat in a different way) and heights (offering shade) can create convective air movements [85]. Kong et al. [35] analysed the effect of wind flow on a street canyon with trees, and Gromke and Ruck [86] probed the influence of two walls over a canyon vortex with perpendicular flow. This fact could help us to understand this environmental phenomenon. For this reason, the present study is suitable for modelling with a high degree of detail (aerobiological and meteorological data at an hourly scale) the environmental impact associated with one pollen type (*Pinaceae*) and its relationship with green infrastructure and the impact on buildings to establish and represent future models for urban planning.

Kubota et al. [87] studied the impacts of land use changes to propose green strategies. These authors analysed the effect of air temperature and wind speed and direction at several heights at 3-hour intervals in several conditions: built-up area, irrigated cropland and pasture, mixed cropland, mixed shrublands and mixed forest. The daytime peak air temperature in the master plan conditions was projected to maintain almost the same level as the current condition. However, high temperature areas would be broadly more abundant in the planned built-up areas. Yeo and Yee [17], in the development of an automated modeller of environment geographic information systems (E-GIS) for eco-friendly city planning, considered aspects such as planned city GIS, 2D GIS layers, the formation of 3D building volume and the formation of 3D urban GIS and aerial imaging to create a conceptual model. All these bearings were applied in our study to complement the shortage of effective methods for evaluating the distribution of buildings to plan and manage their arrangement in green spaces. Tong [18] proposed an index of distribution (IOD) based on a genetic algorithm to describe the distribution pattern of buildings in green spaces [18] such as public parks, and they argued that the scale of single buildings or the distribution of the building group will affect the local ecological environment and landscape significantly. Our study analysed the composition of elements of a green infrastructure and environmental conditions in more detail.

From all project management domains associated with BIM in a study by Ding et al. [8], safety, quality and schedule management are most related to those of the present study. This study adopted a 3D model to ascertain the coupled effects of building-tree arrangements on outdoor *Pinaceae* pollen. Another atmospheric parameter ($PM_{2.5}$) was evaluated in terms of height influence [37]. The results represent an advance for improving public health awareness and have benefits for urban planners in architectural and tree planting design to create a comfortable and healthy environment.

BIM technology allows 4D analysis [14]. Fig. 10 shows a wind direction of 123°, from the largest mass of pine trees to the samplers, with a velocity of 0.36 m/s. This result corresponds to the highest pollen concentration of this hourly episode. In addition, the highest hourly concentration of pollen occurred in the terrace sampler (3866 grains/m^3), in contrast with a concentration of 1091 grains/m^3 in the garden. This result shows that the pines trees in the area surrounding the building also affected the terrace sampler and that wind speed is not sufficient for the pollen to reach the garden sampler. This finding is consistent with the results of Sharma and Khanduri [52], who showed that the distance reached by the *Pinus* pollen shows logarithmic decay; the pines closest to the building are in the most effective range. However, the study by Sharma and Khanduri [52] did not mention the influence of wind speed, which shows a statistically significant correlation with *Pinus* pollen concentration [50]. One hour later (Fig. 10b), the wind direction remained similar (106°), but the speed wind had almost doubled (0.61 m/s). We observed that the difference between the pollen concentration of the terrace sampler and the garden sampler was small. Indeed, higher wind speeds resulted in pine pollen from the closest environment reaching the garden sampler. Finally, 1 h later (Fig. 10c), the wind direction changed (214°), and the speed doubled (1.19 m/s), which caused the pollen input to arise mainly from the pines in the garden. In this situation, the highest concentration of pollen occurred in the garden sampler, 3035 grains/m^3 compared to 1868 grains/m^3 on the terrace. This result shows the influence of the distance of the sampler on the concentration since the greater mass of pines on which the wind indexes was within the 50 m radius of action of the garden sampler and somewhat further away from the terrace sampler.

Our results showed that local air quality is strongly dependent on the relationship between meteorological conditions, the presence of vegetated green space and the 3D configuration of the building. The effect of the urban canopy (buildings and trees) on air pollutant dispersion has been shown to be complex and highly spatially dependent. Therefore, the knowledge produced in the application of BIM in urban planning has the goal of optimizing the role of green areas on human comfort and health [88]. The presented integration provides significant opportunities to reduce environmental impacts [1], allowing special attention to be paid to the evaluation of green infrastructures, such as tree plantings [27], and it can provide another set of goals for urban planners and engineers in urban systems for urban (re)-development [20]. Moreover, our findings could help in understanding other parameters in the resilient city concept. For this, it is necessary to consider whether planning for adaptation includes measures that address all types of risk factors and, at the same time, related environmentally, what make cities hotspots of risk [16]. This study represents a first attempt at considering the study area. Although a wider area would provide a more precise modelling, more aerodynamic wind effects would need to be measured, which would increase the difficulties in the interpretation of results.

The novel results of this study could be framed within the new rules of the green cities related to urban sustainability management [19]. Together with several previous comparisons, our study contributes to the development of ecology tools for design and construction, the development of dynamic physical models, and the incorporation of topological interlocking and optimization methods to building construction [89]. A new proposal related to our study is to produce a mash-up visualization of the social sensing environment [74] and to apply the data in real-time progress management [90].

5. Conclusions

Pines trees in BIM models of green areas and modelling of buildings in their environment were studied. Hourly pollen *Pinaceae* peaks did not follow constant hourly patterns in time for the same sampler; however, the average data showed a correlation between spore traps at

different heights and distances. The daily pattern of temperatures affected hourly peaks, but wind speed modified this regular pattern and may even have been responsible for the appearance of two peaks in some cases. Airborne pollen concentration may be higher at higher elevations, depending on building design, the hour of the day and the wind. The results of this study help to define environmental variables (airborne pollen) that should be considered in construction of buildings and how proceed to integrate its modelling in urban planning. Our results showed that local air quality is strongly dependent on the relationship between meteorological conditions, the presence of vegetated green space and the 3D configuration of the building. The effect of the urban canopy (buildings and trees) on air pollutant dispersion has been shown to be complex and highly spatially dependent. So, it will allow technicians to add environmental health criteria in the design of building envelope voids (size, placement and orientation). From all project management domains associated with BIM, safety, quality and schedule management are most related to those of the present study. BIM technology allows 4D analysis in this new line research. Consequently, the novel use of BIM in aerobiology can be a useful tool towards the construction of "pollen free" buildings, considering the nearness of ornamental trees, potential risk of pollen grains, pollen grain dispersion and meteorology for urban planning.

Acknowledgements

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