Analysis of the Spatial Structure of Green Building in the Aspect of Selected Environmental Issues on the Example of the City of Cracow (Poland)

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Abstract. In the era of developing cities, it is extremely important to maintain an appropriate level of quality of the surrounding environment or to improve this level. Newly built buildings are not without impact on the city’s environment. It is important to control and limit their negative impact. Multi-criteria investment assessment systems help with many problems related to urban development. They allow analysis and evaluation of various issues, including those related to the environment. The purpose of this study was to determine the spatial structure of buildings certified in the BREEAM system (Building Research Establishment Environmental Assessment Method) in Kraków by developing a map of their deployment, and then analysing the location of green buildings in terms of selected environmental issues. The selected certification system is one of the most commonly used multi-criteria assessment systems in Poland. The map was developed to assess the current spatial structure of green buildings. On the basis of the map, it is possible to indicate potential areas of the city where it would be advisable to locate a green building that meets specific environmental requirements. In Kraków, it can be noticed that objects with the In-Use certificate are mostly available individually. There are only two small clusters of such buildings. Upon analysing buildings with a final certificate, it can be observed that there are both single buildings as well as small and larger clusters (office parks). These facilities are located near or between the beltways. When analysing the distribution of buildings with the certificate obtained at the design stage, it can be observed that most of them are located near bypasses. Two clusters are located in the southern part of the city, but this is due to the expansion of existing office parks. Comparing the developed map with the location of the combined sewerage system in Kraków, it can be seen that the vast majority of certified facilities are within or in close proximity to the combined network. If in these facilities solutions related to the management of rainwater at the place of precipitation were used, each of them represents a significant relief for the sewage system in Kraków. Due to the fact that some of the green buildings in Kraków are present in clusters, their fulfilment of requirements related to the introduction of greenery to the plot (Land Use and Ecology, Surface water run-off and Flood risk categories) may affect the levelling of the urban island heat in the areas where they occur. Most green buildings in Kraków are located along the city’s three bypasses. If these buildings have scored points in the category of Transport for specific activities, then in combination with their location this represents a positive value for the city’s air quality. Among the requirements for green buildings in multi-criteria assessment systems are those whose fulfilment is a particular value for the city’s environment only with a specific location of the building. For this reason, it matters to the city whether the newly constructed buildings are green. The most common positive effects can be expected in the central parts of cities, because that is where the combined sewerage
system dominates, where there are problems associated with UHI (Urban Heat Island) or urban floods. The presence of several buildings near each other also generates a pro-ecological effect.

1. Introduction
In the era of developing cities, it is extremely important to maintain an appropriate level of quality of the surrounding environment or to improve this level. This applies to both the internal and external environment. The idea of sustainable development, often defined in accordance with [1], as a “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” is also convergent with this goal.

The sustainable development objectives set in 2015 by [2] include, inter alia, the protection of natural resources (Goal 12: Responsible consumption and production), the promotion of clean energy (Goal 7: Affordable and clean energy) and adaptation to climate change (Goal 13: Climate action). Goal 11 (Sustainable cities and communities) directs attention to air quality, municipal waste management as well as access to inclusive green areas.

Among the many problems of the internal environment of buildings, the occurrence of building materials emitting harmful substances can be mentioned. In commercial buildings, there are often found rooms with low access to sunlight for the people staying there, and at the same time with a large dose of artificial light. One of the answers to this type of problem is biophilic design, the basics of which are described in [3]. According to [4], the task of biophilic design is to create a good environment for people in a modern built-up environment.

Newly built buildings are not without impact on the city's environment. Already at the construction stage, such an investment affects the quality of air, for example through exhaust fumes emitted by vehicles transporting building materials. These types of objects very often cause an increase in the runoff coefficient from the terrain. Thus, the share of biologically active areas is reduced, and the percentage of impervious surfaces increases in the city. This phenomenon may contribute to the emergence of urban floods. Densely built office buildings may also intensify the effect of the urban heat island. These are only selected examples of the environmental impacts of buildings in the city.

Multi-criteria investment assessment systems come to the aid of all these problems. They allow analysis and evaluation of various issues, including those related to the environment. Their prestige encourages investors to devote more funds to environmental issues. These include systems such as BREEAM - Building Research Establishment Environmental Assessment Method, DGNB - certificate of the German Sustainable Building Association, HQE (High Quality of Environment) certification scheme, LEED - Leadership in Energy and Environmental Design, and the WELL Building Standards certification system developed by the International WELL Building Institute. All of these assessment methods are already present in Poland [5]. These systems allow for the application of multidisciplinary knowledge regarding sustainable development and the adoption of a holistic approach to issues related to the construction and use of facilities [6]. Buildings with multi-criteria assessment certificates may be called green buildings due to the fact that they take into account environmental issues at the design, construction or modernisation stage.

1.1. BREEAM multi-criteria assessment system
One of the most commonly used multi-criteria assessment systems in Poland is the BREEAM system. At the beginning of 2018, according to data from [5], there were 356 buildings in Poland certified by this system, which constitutes over 71% of all certified buildings in this country. The system is present in 81 countries, and up to now, according to [7], over 567,000 certificates have been issued. This system assesses the quality and impact of buildings on the environment, as well as defining the standard of best practices for the sustainable design, construction and use of buildings [6].

BREEAM certificates may be issued for single buildings, environments and infrastructure projects. There are several versions of BREEAM depending, among other things, on the country, type of development and function of the building. We can distinguish technical standards for such development lifecycles stages as communities, infrastructure, new construction, in-use as well as refurbishment and
fit-out [7]. In Kraków, there are present facilities rated in schemes for emerging buildings and for existing ones. Certification schemes are constantly evolving. From time to time, new, improved versions of technical standards appear. The latest schemes include the requirements for new constructions in Great Britain from 2018 [8].

According to information from [7], the following categories are assessed during the certification process: energy, health and wellbeing, innovation, land use, materials, management, pollution, transport, waste and water. Then, for each of the categories, the percentage of achieved points (called credits) is calculated in relation to those possible to achieve. Each category has its own weight, by which the obtained percentage result is multiplied. The sum of partial results gives the final grade. The object can get a grade from acceptable (but only in the In-Use scheme) through pass, good, very good, excellent, up to the highest score - outstanding [7]. It should be added that in addition to the appropriate number of points, critical requirements and minimum requirements depending on the given level of certification should also be met [6].

Certificates issued for existing buildings (BREEAM In-Use) require renewal, and certificates for new buildings are issued indefinitely (final certificates). It should be added that this is a certificate issued in a specific scheme, and these are updated from time to time. There is also the possibility of receiving a certificate at the design stage - this certificate is called Interim.

2. Spatial location of green buildings and environmental benefits

The famous architect Vitruvius already in his work [9] claimed that architecture should be beautiful, durable and useful. The location of the building also determines its usefulness. Some BREEAM system requirements are associated with the location of the object, and in turn there are also such requirements the fulfilment of which in some locations is more valuable for the city environment than in other places. Among the requirements of the certification system important for the natural environment, there are also those whose location in the urban space and in relation to other green buildings is of minor importance.

Among environmental issues related to the BREEAM certification for which the location of the building and the distance from other certified objects is of great importance, current problems related to air quality and adaptation of cities to climate change have been selected. The influence of the location of green buildings on rainwater management, urban heat island and air quality has been discussed and analysed.

2.1. Adaptation of the city to climate change

2.1.1. Rainwater management. In the aspect of rainwater management in urbanized areas, the location of green buildings is important. In the certification process, various solutions are promoted that contribute to the management of rainwater at the place of its formation. This is particularly important in city centres, because usually there is a combined sewerage system. Currently, during the adaptation of cities to climate change, any way to relieve the system of combined and rainwater sewage is desirable. The effect is increased if there are several objects at a small distance from each other using alternative methods of rainwater management.

In the "Water" category, which essentially considers the protection of natural resources by minimising water consumption, investments can also receive points for solutions that can contribute to the management of rainwater in its place of formation. According to the 2009 scheme and its guidelines [10], points (credits) were obtained, among others, depending on the calculated water consumption per person per year. Included in this way, among other things, water used for flushing the toilet. In order to achieve a certain level of water consumption, it was possible to use rainwater for flushing toilets. The following guidelines from 2013 [11] also provided for credits for minimising the use of tap water, and one of the ways to do so was rainwater collection. The guidelines [10] also included points for using rainwater in irrigation systems, whereas in later guidelines [11], the issue was extended. Credits could be obtained for the use of rainwater for purposes where no tap water is required - not only for watering greenery, but also for example for car washes. On the other hand, in the guidelines for existing buildings [12] in the category of "Water" in part 1, points can also be obtained for the sustainable use of water,
that is, among other things, the use of rainwater instead of tap water. In the same category, in part 2, in the Water Recycling issue, credits for the use of water from alternative sources of supply, including rainwater, have been provided for.

In the "Land Use and Ecology" category in [10] there is a possibility of using green roofs (or other Sustainable Drainage Systems - SuDS) as a measure adopted to strengthen the ecology of the place. The same entries can be found in a later scheme from 2013 [11]. At the same time, the use of SuDS, including green roofs, reduces the risk of urban flooding. In this category (Land Use and Ecology) in the requirements for existing buildings [12], points can be earned for planting surface vegetation. These can be both horizontal and vertical plantings, i.e. green roofs and green walls.

The problem of building flooding appears in the Pollution (Flood risk) category in guidelines [10]. Its task is to encourage taking measures to minimize the impact of flooding on buildings in areas with medium or high flood risk. As a source of danger, surface runoff and floods from sewers are considered, among others. In the following instructions [11], the structure of these entries has been slightly changed - instead of the "Flood risk" issue, the issue "surface water run-off" covering these issues appeared. In the guidelines for existing buildings [12] in the "Pollution" category (part 1) in the "Impact mitigation" issue, points can be obtained for measures to minimize surface runoff, including planting (including on the roof), permeable surfaces or SUDS.

2.1.2. Levelling the urban heat island and its effects. If investors decide to use the green roof as a "response" to one of the requirements set by the BREEAM certification system (whether as a measure to enhance the ecology of the site or protection against flooding), of particular importance are the number of buildings with these types of solutions and the total surface area of green roofs. In many publications [e.g. 13], information can be found that green roofs contribute to the levelling of the urban heat island (UHI). This is because green surfaces are cooler than the surrounding built-up areas and cause microcirculation to revive and cool the air [14]. The more buildings with green roofs in near proximity in the central part of the city, the better effects should be expected. Green roofs on the outskirts of the city will not be that important in this respect.

Research carried out by [13] confirms that green roofs reduce the heat flow through the roof and thus reduce the energy demand for air conditioning of the building, and thus also reduce the effects of UHI in the building, but this is a separate issue related to the supply and consumption of energy in the building.

2.2. Air quality
Many factors affect the air quality in the city. One can also include the manner of surface management, and in particular the share of biologically active areas. This issue is particularly important in those areas of the city that are poor in green areas. This takes on a lesser importance in areas with a high ratio of biologically active areas or which in the immediate vicinity of such areas. Green roofs, green walls or other areas planted with vegetation supporting the fight against surface run-off in city centres are also important for the air. However, green areas are just one of many factors related to air quality.

One of the most important factors related to air quality is transport, and emissions associated with it. Involved parties should strive to limit the movement of private cars, and the BREEAM guidelines help to achieve this aim. According to guidelines [10, 11], credits may be obtained for locating investments in places with access to public transport, and encouraging users to use alternative modes of transport through appropriate infrastructure (including: electric recharging stations, cycle storage spaces), or limiting space for parking on the investment site. In the requirements for existing facilities [12] points can be obtained for similar investments - provision of cycle facilities or access to public transport. These activities are of particular value for facilities located in areas of the city that are particularly vulnerable to air pollution. These are usually the central parts of the city and around the thoroughfares.
3. Purpose of the study
The aim of this study was to determine the spatial structure of buildings certified in the BREEAM system in Kraków by developing a map of their deployment, and then analysing the location of green buildings in terms of selected environmental issues.

4. Research material and methodology
Among green buildings, only BREEAM certified buildings were considered in the study due to the fact that the most of them are in Kraków. In the Malopolskie voivodship, buildings with the BREEAM certificate constitute over 85% of all certified buildings according to data from [5].

The study was carried out based on the data from [15] regarding the location of buildings with the BREEAM certificate for a green building and from the international database [16]. Up-to-date information on certified sites under the BREEAM program can also be found on the [17]. On this basis, our own information database was created in MS Excel divided into various types of BREEAM certificates. This database included buildings with a valid certificate for an indefinite period (final certificate), buildings with a certificate at the design stage (BREEAM Interim), and buildings certified in the In-Use scheme, which requires renewal.

The Polish database [15] contains the majority of the of certified buildings in Kraków, however not all objects are reported to it. In turn, the interactive map available on the website [18] contains in some cases some inaccuracies as to their exact location. This is probably due to the considerable length of streets where certified buildings are located. For these reasons, it seemed necessary to develop the discussed map.

The buildings in Kraków with the final certificate were evaluated in two programs - for the years 2009 and 2013, to which detailed guidelines were presented in [10, 11]. Buildings with a certificate at the design stage were also evaluated in schemes from the same years (2009 and 2013) and in a scheme from 2016 [19], while existing buildings were assessed according to the 2015 guidelines [12]. The vast majority of certified facilities are offices. However, there are also hotels and commercial buildings, residential buildings and according to information from [17] there is also an object assessed in the bespoke process. This is an individualised way of assessing buildings that are not considered standard.

The location map of green buildings in Kraków was based on cartographic data from OpenStreetMap.org [20] collected via the resource [21]. During the development of the map of Kraków, the materials of the state geodetic and cartographic resource were used by downloading data from the collections of the state register of boundaries and the area of units of territorial divisions of the country [22]. The map was developed using the QGIS version 2.4 (Chugiak) which is a desktop application [23]. New spatial data in the form of three vector layers was added to the map of Kraków based on the previously discussed sources. Each of the created layers consisted of points corresponding to the locations of individual objects certified for green construction. The first layer (named IN-USE) corresponds to buildings with the certificate in the In-Use scheme, the second (FINAL) - to buildings with the final certificate, and the third (INTERIM) to buildings with the certificate obtained during the design phase. Each object is described by a list of attributes that can be displayed in the electronic version of the map when the object is selected in the appropriate mode. This information includes the ordinal number assigned, the name and address of the building, the type of certificate (also stored in the layer name), the type of building, the year of guidelines according to which the object was evaluated were derived, and any comments. By using three separate layers for in-use, final and interim certificates, it was possible to create a separate map for each of the listed types of certificates and a summary map. This enabled the analysis of the location of buildings with the BREEAM certificate as well as the division into individual types of certificates. Additionally, the I and II bypasses and existing fragments of the third ring road of the city are marked on the map. Legends were created for each map. When adding spatial data to the map in addition to the aforementioned databases, in some cases also the websites of objects with development plans, or other sources were used [24, 25, 26, 27, 28, 29, 30] for the exact orientation of buildings. This concerned office complexes in the form of parks covering several buildings.
5. Results and discussion
In the study conducted, 55 objects (or complexes of buildings) with BREEAM certificates (54 facilities in Kraków, 1 near Kraków - in Modlniczka) were included. Each object was included on the map once, even if it had more than one certificate (for example at the design stage and the final certificate). The latest certificate was taken into account. In several cases, when one certificate was issued for several buildings - each building was included, but with the same ordinal number assigned.

The results of research on the spatial organisation of buildings with one of the green building certificates (BREEAM) are presented in the form of a map in Figure 1. This map includes all types of certificates. In the following figures, fragments of the Kraków map with selected objects having one of the types of certificates considered are presented. Figure 2 presents objects with the In-Use certificate, Figure 3 with the Interim certificate, and Figure 4 - with the final certificate.

![Figure 1. Map of Krakow with marked objects having the BREEAM certificate and city bypass I, II and III - own elaboration based on data [15, 16, 17, 18, 20, 21, 22]](image)

Considering the distribution of buildings with the division into types of certificates, it can be noticed that objects with In-Use certificate are mostly present individually. There are three small clusters covering two or three buildings. All facilities located in the city with this type of certificate are located near or between the beltways.

Analysing buildings with a final certificate, it can be observed that there are both single buildings as well as small and larger clusters (office parks). Similarly, to buildings with In-Use certificate, these objects are located near or between bypasses. The only exception is the complex of buildings located in the south-western part of Kraków, but in this area there is no third ring road of the city yet.

When analysing the distribution of buildings with the certificate obtained at the design stage, it can be observed that most of them are located near bypasses. Two clusters are located in the southern part of the city, but this is due to the expansion of existing office parks.
Figure 2. Map of Krakow (fragment) with marked objects having the BREEAM In-Use certificate and I, II and III city bypass - own elaboration based on data [15, 16, 17, 18, 20, 21, 22]

Figure 3. Map of Krakow (fragment) with marked objects having BREEAM Interim certificate and I, II and III city bypass - own elaboration based on data [15, 16, 17, 18, 20, 21, 22]
Taking into account the administrative boundaries of the city of Kraków, it can be noticed that certified buildings are located mainly in the central part of the city. In the scale of the entire city, it can be assumed that the spatial structure of green buildings is random, because it is not possible to distinguish evenly or clustered distribution over the whole city area. However, careful analysis and comparison with the outlines of I, II and III of the bypass allow for the identification of several regularities. Seven larger clusters of this type of buildings were observed. Two of them are located at the eastern side of the 2nd beltway, two at the northern part of the third ring road, one between the first and second beltway, and two in the southern part of Kraków. With the exception of the last two and a group of buildings in the western part of the city and one object outside the borders of Kraków, all green buildings in Kraków are located near the analysed bypasses.

Comparing the developed map of the spatial location of green buildings with the BREEAM certificate with the location of the combined sewer system in Kraków, it can be seen that the vast majority of certified facilities are within the reach or in close proximity to the combined network. The exception is, inter alia, several certified facilities located in the vicinity of the north-eastern part of the third ring road and a cluster of four facilities located between the second and third bypasses in the southern part. If in these facilities solutions related to the management of rainwater at the place of precipitation were applied or are going to be implemented, each of them represents a significant relief for the sewage system in Kraków.

Due to the fact that some green buildings in Kraków are present in clusters, fulfilment by them requirements related to the introduction of greenery to the plot (Land Use and Ecology, Surface water run - off and Flood risk categories) may affect the urban heat island equalization in areas in which they appear.

**Figure 4.** Map of Krakow (fragment) with marked objects having the BREEAM Final certificate and their larger clusters and I, II and III city bypass - own elaboration based on data [15, 16, 17, 18, 20, 21, 22]
Each reduction of exhaust emissions in the central part of Kraków is important for the quality of air and the environment, although in the face of the threat of smog, this also applies to regions that are particularly vulnerable to this phenomenon, and practically - to the entire city. Most of the green buildings in Kraków are located along the three bypasses of the city, i.e. areas exposed to the emission of exhaust gases associated with high-intensity car traffic. If, among many requirements of the BREEAM certification, these buildings have scored points in the category named Transport for the activities discussed in chapter 2.2, in combination with their location, this is a value for the city's air quality.

6. Conclusions
Among the requirements for green buildings in multi-criteria assessment systems are those whose fulfilment is a particular value for the city's environment only with a specific location of the building. The most common positive effects can be expected in the central parts of the cities, because that is where the combined sewerage system dominates, there are UHI problems and urban floods. The presence of several buildings near each other also generates an ecological effect.

The developed map allowed to assess the current spatial structure of green building. On the basis of the map, potential areas can be indicated where it would be advisable to locate a green building that meets specific environmental requirements.

This map can be a support for determining future directions of building development in the city. It can help in setting priorities in future requirements for investors, especially those building in the city centre.

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