GREEN SPACE DEVELOPMENT MONITORING FOR THE SMART CITY: A NOVEL AI BASED METHODOLOGY FOR THE ASSESSMENT OF URBAN GREEN

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ABSTRACT

Since 2008 more than half of the world's population lives in cities with a growing tendency (United Nations 2019). Already now the building sector is energy intensive and accounts for 40% of nations' total energy consumption. As roofs take up about one quarter of total urban surface areas, greening them offers a huge potential for energy saving and can positively affect cities' microclimate. Similarly, green facades grow in importance for addressing rising temperatures due to climate change and provide an efficient use of space in densely populated environments. In general vegetation will play an important role in future urban planning and therefore a resilient method for monitoring is needed, which requires the formulation of a green vegetation metric that is easy to apply and evaluate. A common metric that is currently in use in several German and Austrian cities is the green volume (GV) number, which is a normalised score that describes the total volume of green mass per lot. However, the GV number can give rise to misleading results as it is a quantitative score rather than a qualitative one. As of now the GV number does not reflect ecological aspects or planning considerations like rainwater seepage as well as roof and facade greening. Therefore, we introduce a green space development monitoring methodology that enhances the traditional GV number by addressing the afore-mentioned shortcomings. The proposed metric offers a huge potential to develop artificial intelligence (AI) based automatic green space monitoring. The effectiveness of our methodology is demonstrated in a case study of the city of Klagenfurt, Austria. The results clearly show the increased informative value of the proposed metric compared to the classical GV number.

KEYWORDS _ *Smart City, Urban Planning, Climate Sensitive, Green Space*

INTRODUCTION

Currently more than 50% of the world's population live in urban areas, which is expected to increase to 68% by 2050 (United Nations 2019). As a result of high-density buildings, sealed areas grow at the expense of green and open spaces (Yu 2016). The number of excessively hot days is increasing due to climate change and the urban heat island phenomenon (Kromp-Kolb 2014). Hence, the living quality of the urban population is declining. An effective measure to counteract this downward trend is the efficient and sustainable planning of green spaces.

Roofs span about one quarter of the urban surface and offer together with facades a large potential for greening densely populated environments. Green roofs and facades can help to save energy and to improve the microclimate by heat absorption and water evaporation. Further, they reduce ambient noise and amplify natural sounds (Veisten 2012). As a result of continuous urban growth and an increased need for sustainability and climate resilience cities need new metrics and tools for planning, protecting and managing of limited resources. Therefore, efficient methods for monitoring existing green infrastructures are essential for future city planning. Hence, a green vegetation metric is needed that can be used to assess the qualitative and quantitative aspects of plant ecosystems while being easy to evaluate in an automized monitoring process.

Most green space metrics focus on a two-dimensional (2D) concept. They partition a plot of land into subspaces that are weighted according to the quality of ecosystem services. However, these approaches fail to map facade greenings realistically as their area is difficult to integrate in top view-based concepts. Further, more voluminous vegetation has a higher impact in terms of shading and cooling, which cannot be grasped in a 2D approach. To the best of our knowledge the only three-dimensional (3D) metric is the so-called green volume (GV) number (Grossmann 1987). It is applied in several German and Austrian cities to describe the amount of green per lot. It is a normalized score that is quantitative rather than qualitative, thus, it can give rise to misleading results. For instance, the GV number does not take into consideration the ecosystem services as well as roof and facade greenings.

Therefore, we propose a novel 3D green vegetation metric that addresses the shortcomings of the GV number in its current form, while maintaining its ease of application. The effectiveness of the new measure is demonstrated in a case study of the city of Klagenfurt, Austria. Further, we outline the potential of the proposed metric in automatic green space monitoring using artificial intelligence (AI) techniques.

URBAN GREENING AND LAND USE: Urban green infrastructure plays an important role in mitigating the effects of climate change (Ring 2021). It contributes to cities' liveability and sustainability on ecological, social and political level. Due to this multifunctionality, landscape architecture sees an increasing demand for a standardised description methodology for green spaces in BIM.

BENEFITS OF URBAN GREEN: The positive effects of urban green are manifold ranging from political to social and from economic to aesthetic services. A key benefit is the reduction of the urban heat island effect due to the cooling capacity of vegetation (Ring 2021). Air filtration and noise reduction enhance human health and reduce emotional stress and thus, the prevalence of respiratory and heart diseases is lowered (Jaafari 2020). Green infrastructures are visually pleasing and provide space for recreational activities, which have a positive effect on physical and mental health. Further, green spaces provide natural habitats for various plants, fungi, animals and micro-organisms. They preserve the natural soil function, the performance of the biological water balance and the evaporation capacity.

With the constant growth of cities and the limitation of open space, green roofs and facades play an increasingly important role in urban planning. Aside from the afore-mentioned positive aspects, building users can benefit from a higher durability of green roofs and walls, lower energy demand and reduced sound transmission (Besir 2018). However, green roofs and facades are currently not sufficiently reflected in the evaluation of building permits due to a lack of meaningful 3D measurement metrics and standardised description possibilities.

GREEN METRICS FOR URBAN PLANNING: Most green metrics in urban planning only partially reflect the increasing demands on monitoring and development of green spaces in modern urban environments. Common 3D metrics like the GV number simplify the complex structure of green ecosystems by representing them as simple volumetric bodies to calculate the proportion of plant volume to surface area. This approach creates an easy-to-use tool for municipalities and planning departments but is neglecting qualitative differences between various types of plant ecosystems. To mitigate these shortcomings and prevent circumvention of environmental regulations the GV is usually augmented with other metrics such as a Soil Function Factor (Grossmann 1987). Helsinki's Green Factor Tool (City of Helsinki Environment Centre 2014) introduced a green factor scoring based on four criteria: ecology, functionality, landscape and maintenance. Both approaches focus only on a few aspects, which has led to the development of more holistic approaches that integrate ecological and planning-related aspects into their metrics. Berlin's Biotope Area Factor (Senatsverwaltung für Umwelt 2021) is based on a set of land cover categories where each category is associated with a factor according to its ecological and microclimatological value. The covered area multiplied with this factor is then used to calculate the proportion of biotope area relative to the total lot area.

All these approaches are based the 2D surface area and have therefore difficulties to provide adequate metrics for the 3D use of space such as green facades and on slanted roofs. A new and fully 3D approach can fill this gap and provide a valuable planning tool.

GREENING IN THE BIM SUBMISSION PROCESS: Especially in densely populated regions, roof and facade greenings offer additional potential for green spaces. Currently, there is no standard to incorporate these types of landscape architecture in BIM model data bases. In the Green BIM project (Stadt der Zukunft 2023) a set of criteria based on existing building greenings is created to integrate greening planning directly into BIM planning. In this context, not only green spaces in the scope of building planning are considered but also the execution, care and maintenance of green areas. Thus, in future it is favourable to incorporate the international standard for data structures in the construction industry (ISO 16739 – Industry Foundation Classes IFC) to enable planning and LifeCycle integration in BIM. Further, the BRISE-Vienna project (Krischmann 2020) developed a comprehensive authority submission process based on BIM, which includes automatic and semi-automatic verification of building laws and regulations using checking routines. The project also relied on the open data standard IFC. Based on the results of the two afore-mentioned projects and the proposed 3D green vegetation metric BIM-based requirements for greening can be demanded or automatically checked directly in the submission process.

DEVELOPMENT OF GREEN VEGETATION METRIC

A new three-dimensional metric for monitoring and evaluating urban vegetation is developed based on lessons learned from existing metrics. Hence, relevant vegetation classes are identified with a special focus on roof and facade greenings before describing the actual green vegetation metric.

IDENTIFYING VEGETATION FORMS: Unsealed areas with natural vegetation are clearly most beneficial in providing the afore-mentioned ecosystem services, cooling and health effects. Due to the limited amount of such in urban environments, roof and facade greenings are becoming increasingly important. In general, three main types of roof greenings are distinguished based on the characteristics of the underlying substrate, namely, extensive, intensive and semi-intensive roof greenings. Extensive roof greenings are characterised by a low substrate thickness (<20 cm) and low maintenance needs. Thus, mostly undemanding vegetation with a low green volume is cultivated. In contrast, intensive roof greenings require a higher substrate thickness (>50 cm) and maintenance. Semi-intensive roof greening is a mixed form of the extensive and intensive variants. However, different vegetation forms with a higher green volume can be used similar to natural green areas

(Melzer 2020). With respect to green façade, soil and wall bound greening systems are distinguished. In the former plants have a direct connection to the natural soil, while in the latter plants grow in permanent plant containers (Melzer 2020).

WEIGHTING FUNCTIONS: After having distinguished the most common types of green installations on a building, a suitable weighting factor for each category must be identified. During the development of the two-dimensional Biotope Area Factor (Senatsverwaltung für Umwelt 2021) several land cover categories are analyzed to derive a weighting factor, which will be used in the definition of the upcoming green vegetation metric and its evaluation. Table 1 summarizes the most important categories.

Table 1: Weighting factors of pathways and traffic areas as well as building related greenings according to (Senatsverwaltung für Umwelt 2021).

Pathways and traffic areas		**Building related greening**	
Sealed areas	0	Extensive roof greening	0.5
Partly sealed areas	0.1	Semi-intensive roof greening	0.7
Permeable covers	0.2	Intensive roof greening	0.8
Greened covers	0.4	Soil bound facade greening	0.5
Natural green	1	Wall bound facade greening	0.7

GREEN SPACE METRIC: As mentioned before, we propose a 3D green vegetation metric and we do so in a two steps approach. First, we adapt the GV number to consider roof and facade greenings to compensate for sealed areas, before we incorporate the weighting factor for different greening types to reflect the contribution to ecosystem services and the vegetation density.

In order to calculate the GV, the volumes of individual elements of vegetation must be determined. For grass and hedges the volume is calculated from their covered area times the height in metres (m), while the contribution of trees is the volume of their crown. The crown is approximated by a sphere in case of deciduous trees and a cone in case of coniferous trees. The average height of grass is assumed to be 0.1 m. Then the GV number corresponds to the ratio of the total GV per plot of land (GV_{plot}) to the total plot area (A_{plot}), i.e.,

$$GVN_{classic} = \frac{GV_{plot}\ (m^3)}{A_{plot}\ (m^2)}.$$

In order to incorporate roof and facade greenings into the GV number an adapted GV number is introduced. As before the volumes of surface plants are calculated from their area times their hight. The additional volumes for roof and facade greenings (GV_{roof} and GV_{facade}) are calculated analogously. The normalization factor remains unaltered, thus, green installations on roofs and facades contribute equally to the GV number compared to surface green. Ultimately, the adapted GV number reads,

$$GVN_{adapted} = \frac{GV_{plot} + GV_{roof} + GV_{facade}\ (m^3)}{A_{plot}\ (m^2)}.$$

When applying the $GVN_{classic}$ and $GVN_{adapted}$ in real world scenarios, it becomes clear that trees and large hedges have a disproportionately high contribution to the overall green volume. As mentioned, the GV of trees and hedges is the volume of their crowns and bodies, respectively. Hence, it is assumed that these shapes are tightly packed with green, which is on the one hand not the case in reality and on the other hand leads to problems, when a target GV has to be reached during the realisation of a building project. For instance, with the classical calculation method a 1000 m^2 plot of grass and shrubland of height 0.2 m reaches the same GV number as a fully sealed 1000 m^2 plot supporting a single deciduous tree with a spherical crown of about 7.5 m diameter. Hence, we introduce an enhanced GV number that does not only consider roof and facade greenings but weights each category of green and balances the contribution of trees and hedges to the proposed score. To this end, a plot of land is partitioned into $n \in N$ mutually exclusive and collectively exhaustive subspaces $S_i, i \in \{1,\ldots,n\}$ according to the land cover categories present on the plot. Next the volume of the green installations on each subspace is determined and referred to as $V_{s_i}, i \in \{1,\ldots,n\}$. The green volume of all these subspaces is calculated and finally weighted with the factors illustrated in Table 1. In order to balance the contribution of trees and hedges to the overall GV, we consider the so-called leaf area index (Scurlock 2001), which ranges between 0.2 for trees in winter and 16 for tropical rain forests. It describes the ratio between the leaf area and the covered base area. For typical trees in Austria a mean leaf area index of 6 can be assumed. We use the base area (A_{base}) of the tree crown or hedge body and the leaf area index (I_{leaf}) to estimate the surface area of all leaves. In order to derive a volumetric quantity, the leave surface area is multiplied by a factor (f), i.e.,

$$V_{tree} = f \cdot A_{base} \cdot I_{leaf}.$$

Then the enhanced GV number reads,

$$GVN_{enhanced} = \frac{\sum_{\forall S_i \in S} w_i \cdot V_{S_i}(m^3)}{A_{plot}\,(m^2)}.$$

In case that city regulations require a minimum GV number on a plot of land, the threshold value for $GVN_{classic}$ and $GVN_{adapted}$ can be left unaltered, i.e., roofs and facades contribute equally to the GV number as surface green. However, it must be noted that $GVN_{enhanced}$ is usually a lower number compared to the classical and adapted GV numbers. Thus, the threshold value for $GVN_{enhanced}$ must be reconsidered. The decrease is due to the scaling of volumes based on their contribution to ecosystem services and the balanced consideration of trees and hedges.

PRACTICAL APPLICATION

We evaluate the effectiveness of the proposed green vegetation metric based on three model regions in the city of Klagenfurt. We chose these regions based on the presence of different greening types, namely, natural, roof and facade greenings. Ultimately, we outline the application of the proposed metric within an AI based green space monitoring scheme.

CASE STUDY: CITY OF KLAGENFURT

We apply the proposed metric to three different plots in the city of Klagenfurt. The model areas are chosen such that they include multiple greening types and comprise healthcare, commercial and residential facilities as illustrated in Figure 1. In the following these areas are referred to as Plot 1, 2 and 3 going from left to right in the figure. For all the model areas the classical, the adapted and the enhance GV number are calculated and contrasted to highlight the enhanced informative value of the proposed metric. The resulting numbers are presented in Table 2.

Figure 1: Model areas for the evaluation of the proposed green vegetation metric. From left to right Plot 1, 2 and 3 are illustrated. Image source: Stadt Klagenfurt, Abteilung Vermessung und Geoinformation.

Table 2: Comparison of the classic, the adapted and the enhanced green volume number with varying factor for tree and hedge contribution to the GV.

	Plot 1	**Plot 2**	**Plot 3**
$GVN_{classic}$	0.32	0.23	0.01
$GVN_{adapted}$	0.38	0.26	0.03
$GVN_{enhanced}$, f=0,1	0.38	0.26	0.03
$GVN_{enhanced}$, f=0,2	0.38	0.26	0.03
$GVN_{enhanced}$, f=0,3	0.38	0.26	0.03
$GVN_{enhanced}$, f=0,4	0.38	0.26	0.03

As expected, the adapted GV number provides the possibility of compensating missing natural green on the plot with roof and façade greenings. Thus, $GVN_{adapted}$ is greater than (or equal to) $GVN_{classic}$. For Plot 1 and 2 this difference is most striking due to a considerable GV on roofs and facades relative to the total plot area. In contrast to that the enhanced GV number results in a lower score due to the afore-mentioned weighting and balancing logic. Clearly, a weighting factor f between 0.1 and 0.3 for tree and hedge contributions to the GV is empirically most beneficial as for factors greater than 0.4 the GV of trees and hedges is even more emphasised as in the classical GV number. Revisiting the afore-mentioned example of a 1000 m^2 plot of grass and shrub land of 0.2 m height, according to $GVN_{enhanced}$ with $f = 0.2$ at least four deciduous trees with a crown diameter of 7.5 m are needed to maintain the GV on an otherwise fully sealed plot.

OUTLINE: AI BASED MONITORING

All afore-mentioned variants of the GV number can be applied in different fields of environment monitoring and city planning. For instance, artificial intelligence (AI) based green space monitoring can be designed to detect urban green using models that segment relevant areas from aerial or satellite data. If data of the red and near-infrared band are available, plant health can be determined using the normalized difference vegetation index. Further, the volume of green per plot of land can be estimated directly from the data. The proposed green metrics fulfil all necessary requirements for these applications, the most important of which is the ease of calculation.

Aside from green space monitoring, sustainable city planning is enhanced by demanding a minimum GV per lot and evaluating it automatically. In more detail, BIM based requirements for green installations on and around buildings can be checked in the submission process by validating whether the proposed GV is above a certain threshold. In a second step the actual implementation of the green installations can be monitored using aerial image data after a building project is realised. AI based models can detect green on a plot of land and calculate the GV number, which is checked against the building submission automatically. Similarly, plots that were built on before a minimum GV was required can be assessed in this way. Figure 2 displays a schematic flow chart of the green space monitoring and GV validation process. Further, the growth and change of the vegetation can be tracked and monitored to detect the demand for maintenance. From a city planning perspective either incentives for GV fulfilment or fines for non-fulfilment can be installed to achieve an increase in urban green volume as required by governmental programmes (Umweltamt 2019).

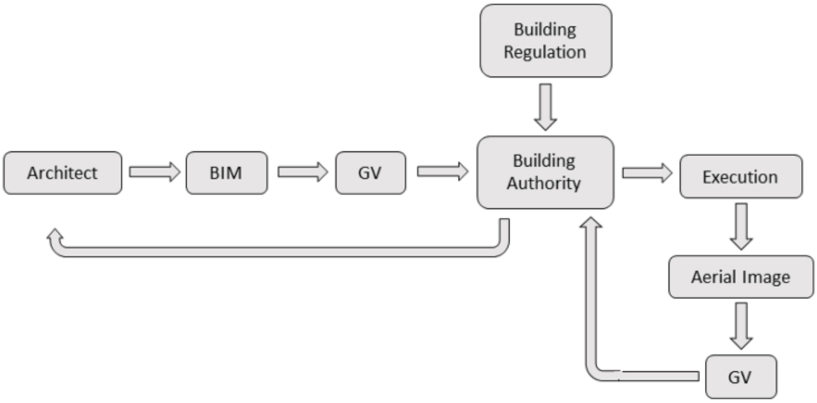

Figure 2: Schematic flow chart of an AI based green space monitoring and GV validation.

CONCLUSION

We proposed two novel 3D green vegetation metrics based on the GV number, which address the classical GV number's major downsides, namely, the neglect of roof and facade greenings as well as the overemphasis of the green volume of trees and hedges. An adapted GV number is introduced to consider roof and facade greenings as equal contributions to the overall GV on a plot of land. Going a step further, the enhanced GV number uses the notion of the leaf area index to enable a more realistic consideration of trees crown and hedge body volumes. A scaling factor is used to control the impact of tree and hedge contributions to the overall GV. Both metrics clearly draw a more realistic picture of green installations in urban areas compared to the classical measure. We demonstrate the application of the proposed metrics based on three model regions in the city of Klagenfurt. Ultimately, we outline the application of the proposed metrics in AI based monitoring to assess the expansion and health of green spaces based on aerial image data. Additionally, an automatic process to check the green volume on a lot against the requirements of the building submission is described. In future work, we will investigate the application 3D laser scanning to estimate the density of green of the most common vegetation types including grass, which was not considered thus far.

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