DETERMINING FRANKFURT'S SUITABILITY POTENTIAL FOR THE ONTOP CONCEPT

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ABSTRACT

The OnTop Project performed at Frankfurt University of Applied Sciences, competing in Solar Decathlon Europe 2014, aims to demonstrate an approach to the rising challenge of urban densification by the help of an extra construction on top of an already existing building. While architects work on the most profitable structure of the building, it is equally important to detect which buildings are actually suitable for this purpose. Through the spatial data (3D city model, solar-roof and buildings cadastre, orthophotos, thermal images and LiDAR data) an analysis was conducted, deriving acceptable buildings within Frankfurt meeting the appointed criteria. Unfortunately, data protection issues and the aim of making the entire analysis automatic left only few criteria usable. Some of them proved to be crucial: height, function and roof surface, while others were used to weigh the results and appoint each building to a suitability class. For instance, the concept assumed that remodelling roofs is acceptable. It was stressed that no resettlement should occur. Therefore, one of the most essential criteria was to assess from the available data, whether a building's attic is inhabited. This question was mainly assessed by the derived average roof angle per building, small angles indicating less likely habitation. One of the biggest challenges of the project was to manage the huge amount of data, their accuracy and inadequacy as well as their different origins. The analysis yielded estimations, overlaid on building polygons, which may be used for this concept and further evaluation resulted in a possible number of built OnTop structures.

INTRODUCTION

Sustainable development confronts humanity with many challenges and there are many ways of achieving it. One of them, addressed in this article, is preventing urban sprawl with a simultaneous energy-saving approach. There have been many initiatives raised to address those matters; one of them is Solar Decathlon. Originated in USA, 2002, the program challenges university teams to design, build and operate solar-powered houses that are cost and energy efficient and at the same time attractive. The program proved to be a success and was introduced to Europe and China. An announcement was signed in 2007 between the U.S. and Spanish governments to create Solar Decathlon Europe. Spain hosted the two first editions of the competition in 2010 and 2012. In 2014, it was held in France (1). "Although these are based on the rules of the American competition, there are important differences regarding the documents the teams shall periodically deliver and on the subject of the contests, more focused on sustainability, energy efficiency, innovation, and research aspects" (2). The idea of the challenge remains the same, but every team addresses the problem with its regional approaches. The OnTop Team was created at University of Applied Science Frankfurt am Main when the University was granted entrance to the competition. What makes the OnTop project unique is the fact that, apart from considering the structure, materials used or energy effectiveness, it also undertakes the issue of placement.

For the first time in history, more than half of the human population is living in urban areas (3). Increasing urban density is a challenge to western civilisation, but not exclusively anymore. By 2030, the number of people living in cities will increase to almost 5 billion, with urban growth concentrated in Africa and Asia. While mega-cities have captured much public attention, most of the new growth will occur in smaller towns and cities with less resources (like social and technical infra-

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structure, access to clean water etc.) to respond to the magnitude of change (4). To address this delicate but important matter, the OnTop team has decided to put their designed structures "on top" of existing buildings. Therefore, the idea puts the emphasis on creating new, affordable living space, renovation of the existing buildings and extension of the existing infrastructure. This applies especially to Germany with approximately 70% of the population living in urban areas (5) as well as to Frankfurt, the centre of the Rhine-Main metropolitan area, where the rising urban density and demographic change are additional challenges. While a team of architects and civil engineers focussed their attention on the superstructure, the point of its allocation emerged. As the idea of building new, affordable living space within the city boundary is considerably appealing and potentially realizable, clearly more than one building had to be identified for this purpose. The study area was the city of Frankfurt. Thus, a concept of determining Frankfurt's potential to suit this purpose was developed. Then, a set of criteria, that a potential building should meet, was agreed on. So the aim of the project was to determine, which buildings within the Frankfurt city borders are suitable to be used as a base for the OnTop superstructure. In order to derive those buildings, GIS analyses based on the available geodata have been performed.

METHODS

Input data for the project included: 3D city model, solar-roof and building cadastre, orthophotos, thermal images and LiDAR data, all acquired from Frankfurt's Surveying Office. Unfortunately, not all of them proved to be useful for the analysis – the 3D city model had LoD 1/2 with no attributes, the solar-roof cadastre was decided to be used in further studies, if at all (described below), and thermal images were supposed to be used as an indicator of inhabited attics (if they are warm, they are heated and can therefore be assumed to be inhabited). Unfortunately, a small sample carried out for ca. 20 buildings proved the assumption to be wrong. Thus, the number of criteria based on the remaining data was increased. Preliminary criteria listed in Table 1 were established to be taken into consideration.

Table 1: Preliminary criteria for the analysis.

Criteria	Indicator	Execution
Function	Residential building	Considered
Height	Max.19 m	Considered
Building area	> 50 m^2 (80 m^2)	Considered
Roof angle	< 45°	Considered
Uninhabited attic	Dependent on the slope	Considered
Surrounding buildings (overshadowing)		Not yet considered
Year of construction		Not yet considered
Appointment in the Site plan		Not yet considered
Monument protection		Not yet considered

Newly built superstructures had to be realized on the houses within housing estates, as only those are capable of providing suitable, existing infrastructure without significant expenses. The psychological aspect was also taken into consideration here, as one would probably not like to live on top of a police station or school for example. The height value was set due to the Hessian Building Law (according to §2 Abs. 3 HBO (Germany)) which states, that each building higher than 22 m (understood as the height above the averaged terrain surface of the upper edge of the unfinished floor of the highest storey, where a permanent residence is available or possible) is regarded as a high-rise building subject to a different law, for instance, different fire-fighting procedures etc. If the assumed height of the superstructure for one storey is 3 m, then all of the buildings lower than 19 m (counting up to the last living floor) are suitable for the concept. On all of the buildings lower than 16 m, a two-storey superstructure can be built, which makes them even more relevant, as the density can be raised. The minimum footprint area was established at 50 m^2. Unfortunately, it was not possible to consider all of the preliminary criteria. Overshadowing is one of them. Although a Solar-

Roof Cadastre (6) including overshadowing calculations is available for Frankfurt, the rules applied there cannot be transferred to this analysis, one and two-storey buildings can be built (differences in overshadowing) as well as their roof orientation can be adjusted to serve the best possible exposition (south exposition at around 35° angle for solar panels). The idea also assumes that OnTop structures should aid the buildings on which they are built, providing as much as possible energy generated from solar panels. Therefore, the buildings with poor energy efficiency should be given priority. Such information can be derived, for instance, from the year of construction, since mostly old buildings with old technology are energy insufficient. Unfortunately, such data could not be obtained for the city of Frankfurt due to data privacy. It was equally important to ensure that site plans and protection of monuments allow such superstructures to be built. Neither Frankfurt's Planning Office nor the Office for the Preservation of Monuments have spatial databases which can be cross-referenced to verify which buildings are protected from any arbitrary remodelling.

The database provided by Frankfurt's Surveying Office consists of building polygons with numerous attributes. Their appropriate recognition enabled a decision to be made which can be used during the analysis. The first and most important criterion was to deliver all buildings with a habitable function. The database itself distinguished 99 unique functions. Five out of those were chosen (housing, housing including service, communal residence, retirement homes and mixed use incl. housing).

Another step in the analysis was to deliver all buildings with appropriate footprint areas and heights. While the area attribute already existed in the database, the height attribute was not available. Fortunately, there was some information enabling the height to be calculated. The database included attributes with the entrance height, eave height and roof ridge height (Figure 1) as well as the number of floors. According to the Hessian law, buildings are not yet 'high-rise buildings', if the habitable last floor is not higher than 22 metres. Therefore, subtraction of entrance heights from eave heights was used to calculate the approximate heights of the buildings.

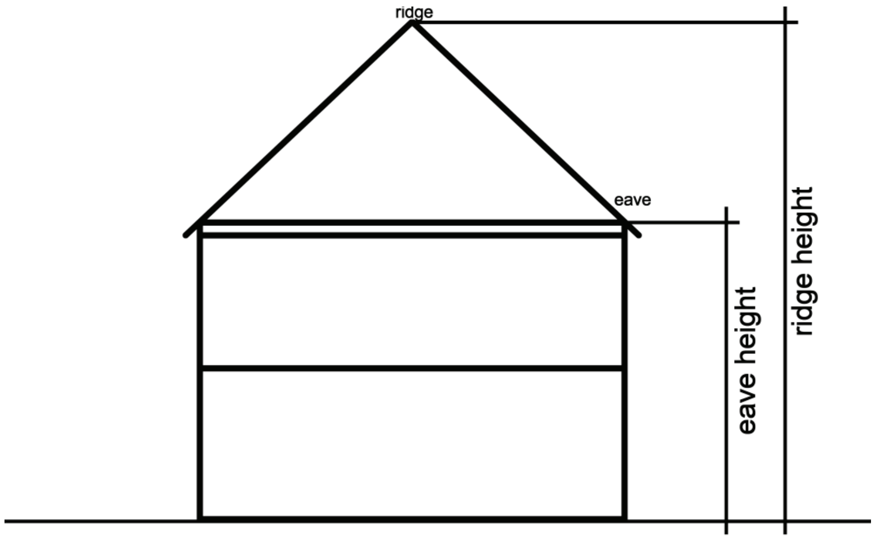

Figure 1: Difference between eave height and ridge height.

Unfortunately, the attributes required for calculating the height value were missing for some of the buildings. Therefore, about 0.2% of the building polygons were removed from the analysis. During the process, another issue emerged – the "function" attributes did not distinguish between bungalows, (semi)detached or terraced houses per se and it was decided not to proceed with them, even when the area was more than 50 m^2. This decision was based on the assumption that the OnTop concept is presumably designed for building housing for more than one family and taking it to such private neighbourhoods and building it on one or two houses would be contrary to common interest. Consequently, also all buildings lower than 8 metres were eliminated from the analysis (Figure 2). Excluding all those polygons decreased the database elements by approx. 2/3 making further calculations easier and quicker. Then, the 'weighted' criteria could be calculated.

The first assumption was to detect buildings with a flat roof or inhabited pitched roof. Unfortunately, the database included information about roof types only - there was no information about whether the roof was inhabited or not. Therefore, it was assumed that all roofs with slopes between 0 and 20º cannot be inhabited, as their attics would be too low to live in. The database did not provide any information about the roof slope, either, so it had to be derived from other datasets; therefore, the next steps of the analysis are mainly based on LiDAR data. Data was acquired in 2010 in 500 m^2 tiles with a density of at least 9 points per m^2. Tiles were first transformed into LAZ files and were clipped with the building polygons and the remaining points were appointed to each building polygon. In the next step, height and slope statistics were calculated. When calculating slope statistics, also many small structures on the roof (as chimneys, dorm windows, antennas etc.) had to be taken into consideration, as they significantly influence the mean slope. Unfortunately, at the time of the project, no quality assessment of the results was made. In this step, points with slope values higher than 60° (for small roof superstructures or chimneys, windows, TV antennas) were ruled out as well as all buildings with roof slopes higher than 45° (the original assumption). However, there are different approaches to tackle this matter, e.g. applying an automatic method for detection and detailed reconstruction of 3D building models that include roof superstructures such as dormer windows or chimneys from a very high resolution Digital Elevation Model (7). The results of the calculation were building polygons enriched with height and slope statistics (min, max, med ect.) attributes. Out of originally 273,348 building polygons, more than 60,000 were left being suitable for the "OnTop" concept up to a point. It was decided to assign on a scale from 1 to 10 (described below) how suitable each building is.

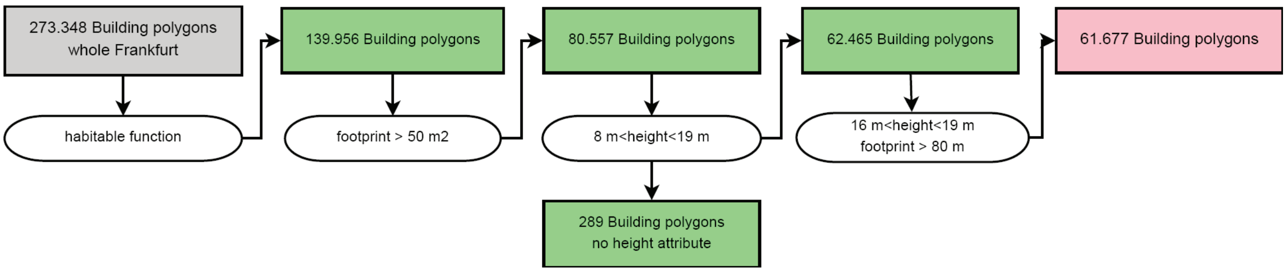

Figure 2: Workflow diagram (hard criteria).

Removing from the database all of the buildings which did not meet the 'hard criteria' meant that the remaining ones are suitable for the concept up to a point. Calculating weighted criteria was to identify the suitability, to assess how many buildings can be used for the concept without huge costs of refurbishing (which means that they presumably had flat roofs) and which ones had to be considered to be remodelled (presumably pitched roofs). They were clustered in classes with appointed weights (Table 2) in order to show their suitability.

Table 2: Results and appointment in each class.

Class (weight)	Height		Slope		
	<16m	≥16 m	0°	0°-20°	≥20°
I (10)	•		•		
II (8)	•			•	
II (7)		•	•		
III (6)		•		•	
IV (4)	•				•
V (2)		•			•

All buildings of 16 m or lower with a flat roof are the most suitable for the concept, as a two-storey structure can be built there and the costs are correspondingly low. The flat roof means that their weighting is the highest. Buildings higher than 16 metres are less suitable, as only one floor can be built, but the costs are still low regarding the roof geometry. It was decided that buildings of 16 m or lower with a roof slope of 20° or lower are equally suitable, as the roofs are presumably uninhabited (their attics are too low for people to live in). Therefore, the structure (in this case: two-storey) can be built there after proper preparation of the roofs. Buildings with the same roof geometry, but higher than 16 m, were considered to be moderately suitable, as expenses for refurbishing the roofs would be involved to build only one-storey structures. The two last groups were the buildings with slopes higher than 20°; therefore, their roofs might be inhabited. The original assumption was made that even inhabited roofs can be refurbished, if buildings meet the other criteria. Here, lower buildings (less than 17 m) were more significant, since two-storey structures can be built there.

RESULTS

Consequently, every fifth building of the city is basically suitable for the OnTop concept which corresponds to almost 22% of the existing building stock (60 thousand out of 270 thousand buildings). The visualized results (already clustered into classes) in Figure 3 give a better survey.

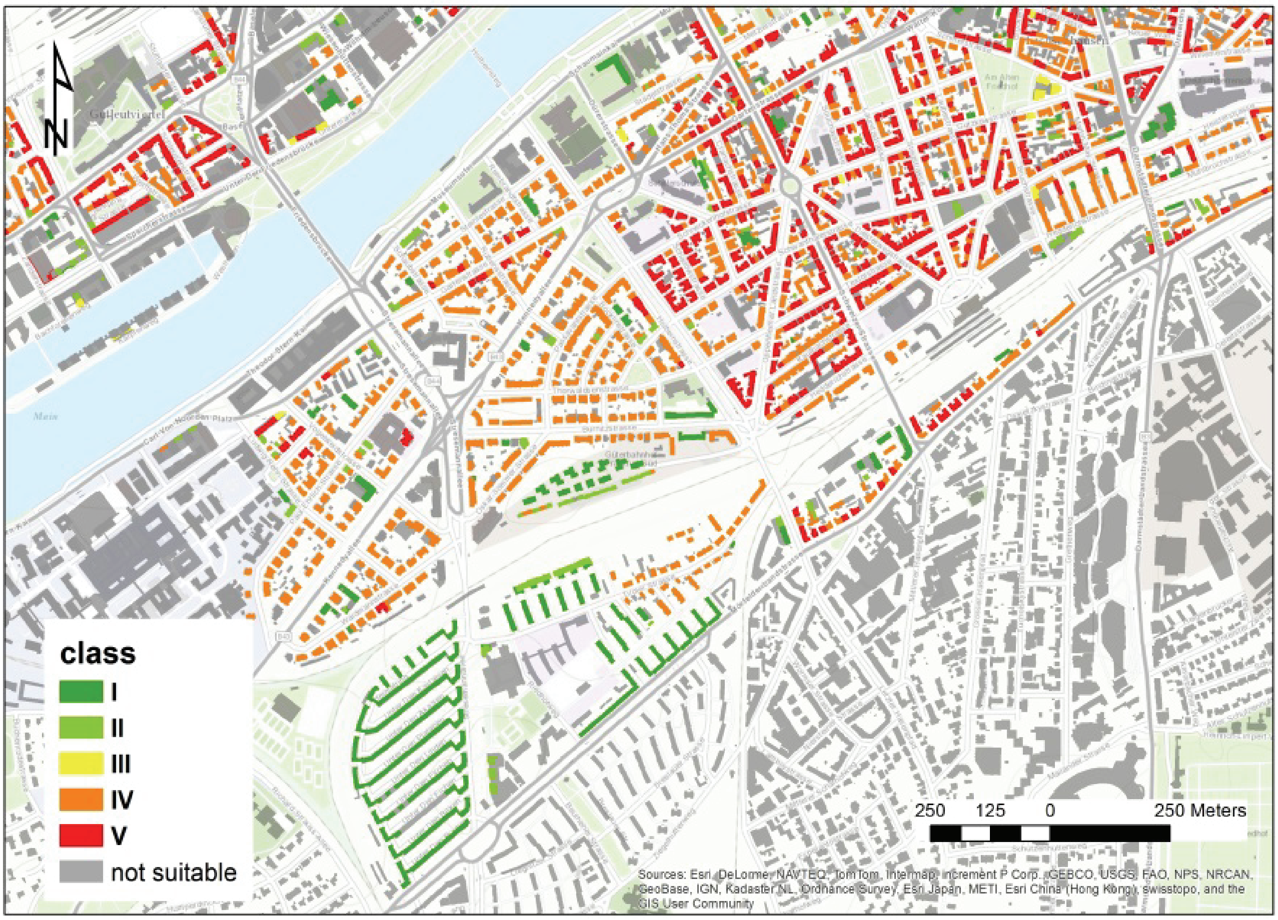

Figure 3: An example view of the result.

About 80% of all buildings that proved to be suitable for the concept are found in the two weakest classes – which means that their roofs are presumably inhabited, as their roof slopes are higher than 20° and that only one-storey OnTop structures can be built on some of them. Therefore, it was decided not to take them into account for further calculations and assessments of the living space that can be provided, because they would probably not serve the purpose. Out nearly 140,000 buildings with habitable function in Frankfurt, more than 60,000 were left after the analysis. If only the first three classes are taken into account, 12,500 building polygons are left, which enables the new living space to be calculated as shown in Table 3.

As mentioned in the beginning, there is a number of other criteria to be considered while performing the analysis. This was the reason for the assessment that only 5% of the whole possible living area created can actually be realized, which adds up to a round two thousand apartments. The 5%

fraction was only an assumption made by the team; in the outline of the project it was therefore suggested to perform further analyses for the relevant statistical sample (8) with extended criteria like: year of construction, appointment in legally binding site plans, which unfortunately vary in their importance (9), data from solar-roof cadastre and data on monument protection. Only then can the results of the study be extrapolated to the results derived here and the 5% assumption be modified and adjusted to the more realistic value.

Table 3: Calculation of possible new living space created.

	Before the analysis (habitable function)	After the analysis	For class I-III
Number of building polygons	139,956	61,677	12,275
Living space in m²	31,521.733[1]		2,649,440
Estimator 5%			132,472
Apartments			~ 2,650

CONCLUSIONS

In the year 2009, the average living area in Frankfurt was 69.86 m^2 per housing unit. From 2010 till 2020, the annual average of housing needed is approximately 27.000 apartments. Between 2020 and 2030, an annual average of approximately 6.000 apartments is estimated (10). Assuming that the average living area in Frankfurt is 69.86 m^2 it is possible to calculate the needed living area by 2030 - 2.305.380 m^2. The results show that such space can be provided by executing the OnTop idea. However, it has to be pointed out, that an estimator (5%) is highly inaccurate. Therefore, for the future research, it is recommended to conduct more detailed studies taking all of the criteria into consideration in order to make the assessment of the estimator more accurate. A close cooperation with Nassauische Heimstätte may enable such an inquiry.

Performing the analysis has also exposed some of the issues of data accuracy and potential sources of errors in the results. As mentioned above, not all of the records included all of the required attributes, which influenced the results of the analysis. Moreover, an issue of the polygon compactness emerged. Due to the architecture of the database, a single polygon does not always mean a single building. Usually, one building consists of several polygons. This led to a few cases, where the building polygon considered to be suitable for the concept (appropriate function, height and area) had an inappropriate geometry (e.g., 5 m wide and 20 m long). The challenge to the existing infrastructure (11) within the building stock that may occur while realising the OnTop concept must also be considered.

All discussed matters should be considered in future research, delivering possibly the best available estimation of how much new living space can be created within existing housing estates to address increasing urbanisation problems.

We should not forget that space is a limited resource, just like coal or gas, and humanity should treat it with equal respect, as it is our common good. While trying to address this matter, renewable energies have to be used, new infrastructure solutions have to be applied and decision-making processes should be supported by GIS analysis as in the present study.

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