DAttE - Detection of Attic Extensions

Workflow to analyze the potentials of roofs in an urban environment

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European cities like Vienna are characterized by strong growth and, as a result, by high demand for living space. Extending the attic is one way of meeting this demand. However, there is a lack of data to know which roofs are already expanded and to what extent. The city is interested in the data in two ways: firstly, in relation to the distribution of potentials (a possible change in population density, for example, has an impact on infrastructure and parking space) and, secondly, in relation to the material composition (city as a material resource). This paper provides a workflow to fill this gap of knowledge. The new methods of detecting attic extensions are described and a case study is given at the end to show workability.

Keywords: *point clouds, thermal detection, drone detection, participation*

MOTIVATION

The city of Vienna has, on the whole, a good 3D database of its built environment, however, information about roof extensions is incomplete (In Vienna, attic extensions are not subject to any official registration, which is why there are no exact dates, only estimates; Gruber et al. 2018). On the one hand, this is because of insufficient digital data about submissions of roof extensions (up to a certain year this data is only available in analog form and not connected to the digital 3D city model). On the other hand, regarding rooftops, LOD2 (level of detail 2, which is the level of detail for all buildings of the city) is too imprecise and LOD3 (level of detail 3) data is only available for a few selected parts of Vienna. The goal of this paper is to fill this gap and to provide a framework through which the data can be improved (see Figure 1). There are two main reasons why knowledge about attic extensions is of interest (not only for the city government but also for investors and construction companies): (1) it influences the likelihood of demolition/new construction (the absence or existence of an attic extension gives information about reserve spaces and the probability of possible expansion hence investments), and (2) it improves the knowledge about the city's material resources (regulations on earthquake safety, building physics, and other specifications affect the materials used, which makes such material compositions clearly distinguishable from other constructions).

Attic extensions of the classic so-called "Gründerzeit" houses (epoch in Vienna from 1840 to 1918) serve as an example. These buildings are proven construction volumes that the city administration would like to preserve (apart from tried and tested floor plans, they offer a pleasing external appearance, or

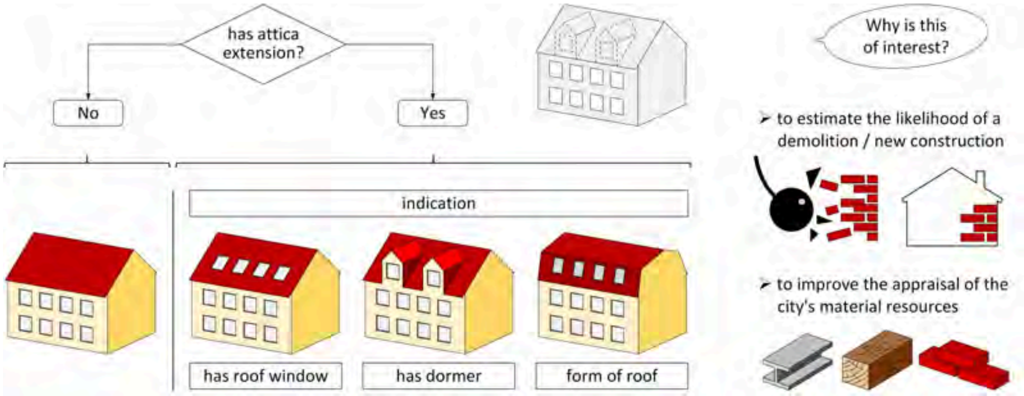

Figure 1
Problem: How to identify attic extensions in order to estimate the likelihood of a demolition / new construction and to improve the appraisal of the city's material resources

are even protected as a historic ensemble). Entirely in line with the wish of the city, the presence of an attic extension reduces the likelihood of a demolition (if at all allowed) not least because such extension usually goes hand in hand with a holistic renovation (from bottom to top). In short, an existing attic extension together with other indices (year of erection, utilization, ownership structure [single owner or community of owners], historic building preservation) gives a good indication about the likelihood of demolition/new construction or possible addition (if allowed by law). Concerning the materials, the outer wall of such a "Gründerzeit" house is typically made of brick, the uninsulated attic of a brick-covered wooden construction, while the floor of the basement mostly simple consists of solid clay. With an attic extension, finally, insulation, steel, and concrete are incorporated. Important for the selection of materials are static requirements, load transfer, but also earthquake protection. In contrast to that, modern buildings consist of stacked stories with flat roofs, made of concrete with thermal insulation composite systems (with more concrete, but far less steel and wooden components).

This paper follows on from a broader project to improve data on cities in terms of material resources (M-DAB: digitize, analyze and sustainably manage the material resources of a city; see Wurzer G et al., 2020). One starting point of M-DAB was to think of buildings within a city as resources that can be reused instead of being disposed of (calculating the exact material resource recovery and forecast their future availability) [1]. This especially is important on the way to a decarbonized future. Since material compositions of existing buildings are (up to now) not digitally available in any database, other methods for material evaluation have to be used. Kleemann et al. (2016) propose an aggregated method that uses (1) existing documents of buildings that are analyzed for the materials used to construct and modify the building, and (2) statistical data that derives from on-site inspection, measurements, and selective sampling before the deconstruction/demolition of the building. Based on this data the material composition of pre-existing buildings can be derived from: the building period (1800-1918, 1919-1945, 1946-1980, 1981-2000, 2001-2015), the utilization (residential, commercial, industrial, and other buildings), and from other information (with/without attic extension, renovated or not). Since the relationship between building data and material composition depends on statistical data, improving the knowledge about the location of attic extensions would lead to a better overall dataset on material resources in the city.

BACKGROUND

Vienna is one of the fastest-growing metropolises in Europe. Seen from the vantage point of limited and valuable space, densification is an option to meet this demand. This includes attic extensions (mainly on "Gründerzeit" buildings) which have the advantage to create new living spaces in more densely built-up inner-city districts; this implies that infrastructure already exists while at the same time no green space has to be destroyed. In 2004 the annual potential was estimated to be 400 attic extensions per year, which lead to a remaining total potential of approximately 9,300 extensions (with 2-3 apartments per unit) (Gruber et al.). Since these are only estimates, a more accurate data set would improve planning security and forecast for the entire city.

The geometric (outer) form of a roof – for example, dormers and other shapes that stand out of the pitched roof – can give a first indication of the degree of an attic extension. (Improved) feature extraction algorithms are already used for roof detection (Yeh 2021). Vienna provides an open-source generalized roof model (level of detail 2, LOD2) of all buildings inside the city borders. The data derives from a semi-automatically process and reflects only prototypical roof shapes but no detailed shapes. However, a solely geometric investigation excludes other possible indications of usage, such as roof windows. Apart from that, the available LOD2 data set is too imprecise and can therefore not be used as the only source. A more detailed roof model (level of detail 3, LOD3) that, eg include details such as dormers, would better indicate attic extensions. However, the city administration of Vienna determines such data only project-related (on the basis of aerial photo evaluations) [2].

Photogrammetry

In the field of architectural building survey different methods are used, which differ both in terms of their precision and their speed: (1) the (classical) hand measurement is time-consuming and its accuracy depends on the care of the person measuring; (2) the tacheometry together with specific measurement software produce precise plan drawings, but is time-consuming when applied to complex buildings; (3) laser scanning generates very quickly point clouds, while the post-process of combining the data of various locations into a 3D representation is time-consuming and complex; (4) photogrammetry, finally, produces with the help of suitable software point clouds, preserving the textures as well (Donath 2008, Willibald 2011, Kals 2019). In most cases, a combination of these methods can be useful, depending on the aim of the architectural building survey, as well as, a combination of UAV (Unmanned Aerial Vehicle) and hand-held photos (Kals 2019).

In our test case, we concentrate on photogrammetry, which is a well-established possibility to obtain digital 3D data of existing buildings. In simple terms, an algorithm determines distinctive points on every image, out of which the camera position and the position of the images in relation to one another are calculated. This underlines the importance of sufficiently large overlaps of the images and, following from that, the importance of defining the flight route at the beginning of the recordings. After determining the rough point cloud follows the generation of a dense point cloud. Finally, a triangulation-algorithm combines the points to editable geometries. Various software systems are available to convert 2D images, taken from different positions, into a point cloud and finally in geometry (the Poisson or Delauney algorithm are possibilities to obtain a polygon mesh representation out of point clouds). During this research, for the process of photogrammetry, two different programs were used: 1) Autodesk ReCap Photo, and 2) Meshroom (AliceVision 2018), which is more or less a GUI for AliceVision (an open-source framework for photogrammetry, developed as a collaboration of several universities together with VFX-Studio Mikros Image in France). Caching is one advantage of Meshroom allowing to pause working on projects at any time in order to be continued later. A disadvantage, however, is that it is slower compared to other software (Hofmann 2018). With Autodesk ReCap Photo, in contrast, overlapping photos are uploaded to Autodesk ReCap Photo. Thereafter a point cloud and a 3D model in various formats are available.

Photogrammetry enables a broad range of applications: eg in combination with VR and AR, it allows users to "walk through" (historical) existing buildings without being on-site, but it also enables to present different configurations of furnishing to a customer (e.g. in event management). For our framework, close-up photogrammetry (Luhmann 2018) with multiple image recordings and digital evaluation is the choice.

Thermographic Inspection

Infrared thermography (IRT) is an investigative technique that displays surface temperature distribution. Since the equipment gets cheaper, IRT areas of application increase rapidly; eg in medicine (monitoring body temperature; see Lahiri et al. 2012), in the industry (detection of motor failures; see López-Pérez et al. 2017), for military purposes (Akula et al. 2011), and in agriculture and food industry (reaching from assessing the seedling viability to the evaluation of the maturity of fruits and vegetables; see Vadivambal et al. 2011). With buildings, thermography not only detects heat losses but also enables methods to measure the insulation values of the building envelope (calculation of the heat transfer coefficient (U-Value) via IRT; see Nardi et al. 2018).

Thermography on buildings is well established to discover different temperatures and subsequently detect thermal bridges (temperature distribution on the component surface as a heat/cold map). According to Entrop et al. (2017), however, there are three modes in which energy can be transmitted: (1) reflection, where the energy comes from the same side of the record; (2) transmission, where the energy is recorded on the opposite side of delivering; and (3) internal, where the energy is generated within an object and recorded externally. With attic extensions, thermal bridging is hardly avoidable (around openings and in the case of materials with less thermal insulation) and is therefore an indication of the expansion stage. The degree of difference between the inside of a building under investigation and the outside air depends on the model of the camera used. Other influencing factors are wind, rain, and direct sunlight. Since solar irradiation affects the result, it is recommended that an inspection should be carried out before sunrise.

The combination of infrared (IR) thermal sensing and Unmanned Aerial Vehicles (UAVs) technologies improve accessibility (and speed). It is only with UAV made possible to examine the top floors and the roof or at least it is made easier to reach these parts of the building. However, regulations (distance to airports, restriction in inhabited areas) limit its use.

Online participation

The participation of the citizens via digital services allows recording and collecting information about a large area in greater detail. With Smartphones and wireless internet, data is permanently available and can be added or adjusted just-in-time. Private associations, as well as public institutions, operate such digital platforms for various purposes. As an example, various cities run the open-source platform "decidim" [3] in order to push for democratic governance. City governments want to encourage their citizens to participate politically and use the collective intelligence to introduce, discuss and implement proposals. The so-called "Leerstandsmelder" (vacant reporter), established in a couple of German and Austrian cities, in turn, allows registered users to report, comment, and update the vacancy of buildings, apartments, bars, and shops (since 2010). Digital platforms, provided by municipalities, also empower their citizens to quickly report sources of danger or malfunctions/problems in the urban space (reaching from broken street lights to potholes). This speeds up identification compared to conventional routine controls by the authorities. For example, with the app called "Sag's Wien" (since 2017) the City of Vienna runs an online service that enables direct communication between citizens and the city administration with just a few clicks [4]. The citizen sends his/her concern as a message via text and optionally with up to three images. Registration is not required. Location can either be located automatically via GPS or by entering an address. For more examples of intended uses and comparisons between various apps see Höffken (2013).

METHOD

All building geometries in Vienna, including rooftops, are available as LOD2 data and freely provided by the government (Stadt Wien, 2020) (The detailed roof model LOD3 shows the exact roof shapes but is not generated for the whole city). The data gives an initial indication of the degree of attic extension (whereby conclusions are drawn from the principal shapes). In order to improve the available geometry, aerial photos and drone flights are used, taking 3D scans and photogrammetric recording (Shariq & Hughes, 2020) (using algorithms to detect and interpret e.g. dormers and skylights). Thermal recordings provide additional information on whether or not (parts of) rooftops are inhabited or not. The improved data is then made available in a web-based open-source 3D environment (see Figure 2).

Digital citizen participation has the potential to improve urban planning (Burak Pak, 1016) and is a common method to quickly get information about public space (eg Brovelli et al., 2016). (Web-based) apps are one possibility, with which, for example, citizens can add data to buildings. This dramatically improves the knowledge about the building stock, especially when homeowners add details about parts of the building (including wall constructions or habitation).

A concept of roof detection from geometry

The first step is to examine the digital data provided by the City of Vienna. To allow automatic detection of the degree of attic extension, every single (geometric) element has to be examined regarding its position within the building. The LOD2 data of the building geometries basically includes three different elements, which consist of several polygon networks: 1) the roof, 2) the building structure (the main floors), and 3) (for most cases) the base area. The affiliation to a single building (-complex) is defined by their allocation on one and the same layer. Since this paper is about a workflow for recognizing the degree of attic extensions (and not about the development of an all-in-one program), the first step has been analyzed with the aid of a little script written in Grasshopper® (for Rhino® [McNeel & Associates, 2015)). It allows to separately examine a single layer (i.e. a building (-complex)). On this layer, the color of the element (polygon network) provides an initial indication of the elements' affiliation. Eg the roof has the color RGB (153,38,0), while the main building structure and the base area are of grayscale (RGB (173,173,173)). A distinction between the base area and the structure is then made according to their height. Since within building complexes, eaves heights can change, it follows an (automatic) detection and subsequently a separation of building parts.

In a next step, the outlines of the roof areas are extracted to define the heights of the eaves of each building (of each layer respectively). That allows recognizing connected areas, which provides further information about the interrelation between building structure and attic. In our approach of developing a framework to detect the degree of attic extension, the focus, for the moment, lies on buildings of the

Figure 2
Improving the data by adding photogrammetric and thermographic information using a drone

Gründerzeit. This is because they are well suited for attic extension (they offer large empty attics with suitable roof inclination) – another reason lies in the fact that, on the one side, there already exist many examples of such extensions, and, on the other side, there is still a lot of potential. In the next step, the normals of each individual surface provide further information about the geometry. The algorithm looks, at this stage of development, for roof inclinations between 30 and 60 degrees. This is because 45 degrees is the maximally allowed slope (Viennese building regulations) if the building height is fully used; but it is also in the range of the typical slope of roofs of the Gründerzeit (35-45 degrees).

Photogrammetry
With photogrammetry, the quality of data and thus the information content about the shape (of roofs) is improved; moreover, it is a possible method of getting the basic shape if no LOD2 model is available. At first, point clouds are generated from photographs taken from different locations and perspectives. Then follows a triangulation to get a 3-dimensional mesh representation. Since mainly roof surfaces are in the focus of our project, drone flights along a predefined flight route are suited for taking overlapping images. It turned out that a circular route around the object is best (compare Kals 2019). In the next step, those images are eg uploaded to Autodesk ReCap Photo and converted into a georeferenced point cloud and mesh. The data can now be manipulated with certain tools in order to narrow down the extraction to a relevant section, eg by removing unnecessary points or triangles. After the preparatory step (see Figure 3, top), both, the 3D model and the point cloud are exported and can be post-processed in other programs. Since the obj file format is a simple data format that represents 3D shapes alone as vertices and texture vertices, it is used by many 3D graphics applications, including Rhino. That's why this format is particularly suitable for transferring the data. It is recommended to reduce the number of triangles before the detection process of attic extensions starts (for the building complex shown in Figure 3 (top) the number of triangles eg exceeds 45.000). The reduction can be performed either directly in Autodesk ReCap Photo or afterward in Rhino. At the moment we use a self-written script in Grasshopper® (for Rhino® [McNeel & Associates, 2015)) that translates the resulting shapes (from photogrammetry) into a form similar to the LOD2 data (see Figure 3, bottom). This allows us to use the same algorithm for the separation of building parts and the detection of roofs as described before ("A concept of roof detection from geometry"). Nevertheless, the correct choice of triangle reduction and the detailed translation workflow are the subject of future research.

Figure 3
Top: Autodesk Recap Photo (Point cloud, triangulation); Bottom: Identification of attic extensions.

Additional information through thermography
The previously described analysis of LOD2 building structures and the photogrammetric recordings, respectively, give a first cautious estimate about the degree of attic extension. However, dormers, cross dormers, extended dormers, and the like alone are not exclusive or unmistakable factors for the identification of attic extensions. Roof windows, for example, are completely excluded, although they provide another indication of the use. One possibility of detecting such an indicator lies in the analysis of satellite images, where roof windows stand out as reflec-

tive or dark surfaces (in contrast to the surrounding roof surfaces that are covered with eg red tiles). However, there nevertheless exist restrictions due to possible (color) variants of the roof and the risk of confusion with solar panels and photovoltaic systems. The latter also holds true for the analysis by means of thermographic recordings, since such surfaces usually emit more heat than their surroundings. Nonetheless, thermography provides important additional information. With a conventional thermal image, window frames distinguish from their surroundings due to greater thermal weakness. This applies both to the window glass (double or triple glazed) and to the well-insulated roof structure. In order to analyze roof surfaces with this method, the recordings are made with drones. By doing so a large area can be reached in a relatively short time. The obvious disadvantage lies in no-fly zones of densely populated areas and above people, but also in the interpretation of the results. The latter includes the definition of the color ranges. The assignment of the thermographic images and thus the temperature profile to the respective roof surface, in turn, is simply done by georeferencing the images. If the roof surface of a building does not display a uniform heat emission, but rather different distributions, then size, and relation to the total surface are further indicators for the degree of attic extension.

Web-based application

With FLÄVIZ (a tool to visualize alternatives of land-use planning), two of the authors have already presented an application that is based on LOD2 data of the building stock, provided by the City of Vienna (Lorenz WE et al 2020). More specifically, it is a web-based application developed in Java Three.js using TDSLoader (3DSMax). Three.js is a JavaScript library that uses WebGL to display 3D graphics in web browsers, while the TDSLoader is a NodeJS wrapper for the TDSLoaderlibrary to convert 3D graphics to Three.js. With the here presented workflow the buildings in question and their roof faces are loaded separately to the model as 3DS-files. An advantage of this procedure lies in a possible combination of the post-processed data set (Rhino/Grasshopper) and the original data set (LOD2 model or data from photogrammetry), which allows adding the terrain model as well.

CASE STUDY

The workflow specified above – from analysis of LOD2/photogrammetry data to the involvement of homeowners – is verified in a case study. Since it is primarily about the workflow and the basic conception of the methods, partly manual data acquisition is used.

LOD2 data analysis

A specific test dataset, provided on the webpage of the City of Vienna, is used for the first phase of analyzing the LOD2 data [5]. This data is available, among other formats, as dxf file, which is at first loaded into Rhino® and subsequently analyzed by an algorithm implemented in Grasshopper®. Further adaption (analyzation and rework) of the LOD2 data is necessary eg to define the geometry of the outer form of an attic. Basically, the data is available as polygon networks that define an outer surface without representing a 3-dimensional shape. Moreover, sometimes they represent a bigger building complex. In order to give the most accurate picture of the roofscape, it is necessary to detect and define single connected roof surfaces first. Accordingly, the original dataset is subdivided into smaller contiguous units. The normal vector on those surfaces yield two different groups: 1) flat roofs, and 2) pitched roofs (or less steeply inclined roofs and their combinations). In the first case, an attic extension is primarily indicated by setbacks of one or two roof stories (number depends on the regulations that limit the roof height to either 7.5 meters or with special indication to 4.5 meters). In the City of Vienna, such setback shapes mainly appear on modern buildings from the 1970ies onwards. However, our initial focus lies in the detection of the degree of attic extensions on top of Gründerzeit buildings which were originally unused. Those attics belong to the second category of less steeply inclined and pitched roofs. It is the course of the outline of the eave that provides an initial indication of the degree of extension. For example, with dormers, the height of the outer roofline not only changes according to the roof ridge but also along the eave (a special case concerns dormers that are set back or dormers in combination with widely projecting roofs; they are indicated as closed polygons inside the outer borderline of the roof).

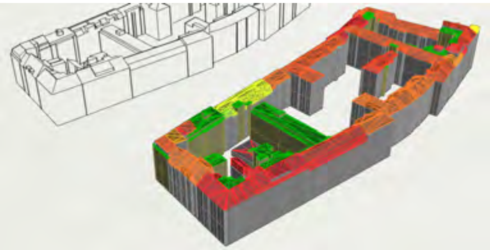

Figure 4
Analysis of the test data: The degree of the possible attic extension ranges from red (with a ratio between the actual volume and the maximum possible of about 0.5) over orange tones to green (with a ratio above 0.9).

The lowest point of the outer roofline, which means the lowest eave point, also defines the lower fictive roof termination of smaller contiguous building units (it is a xy-parallel through the lowest z-value of the roof polygon network). In this way, even pent roofs – which are otherwise only represented as a sloping surface in the LOD2 data – are indicated as 3-dimensional shapes (see Figure 4). The ratio between the so determined volumes and the maximum possible – defined by an extra fully utilized story with a flat roof – gives a first indication of the degree of attic extension. A solely pitched roof with a continuous eave would result in 0.5. The analyzed data so far show ratios around 0.6 for pitched roofs with dormers. An initial conclusion about the attic extension can be drawn based on these results together with the calculation of the face normal vectors of all roof fragments. However, examinations so far have also shown that the representation of the data as polygon networks and their interpretation or further adaption respectively (by dismantling them into smaller units) can cause uncertainty or even errors. Eg dormers that start at the roof ridge are interpreted as separate areas and therefore may lead to higher base areas in relation to the surrounding (the actual roof surface). This is another topic for future research.

Thermography

In our test case, the thermographic and photogrammetric recordings are carried out together during a predefined flight route. This avoids, on the one hand, flying in thermographic mode while on the other hand, both data sets are made available at all. An important difference between the two recordings concerns their resolution, with an image size of 640x360 pixels for thermal images and 4056x2280 pixels for photographs (72dpi each). Especially, the low resolution in the first case causes difficulty for detailed recognition of (roof) windows. Moreover, external weather conditions heavily influence the results. Even unheated attics can show high temperatures in the afternoon of a cold but very sunny February day due to the reflection of the solar radiation, depending on their orientation. Future research will therefore focus on the improvement of the quality of the results and on how to transfer the data onto the Rhino model.

Figure 5
Web-based representation of the information about attic extensions

Web-based representation

The web-based platform developed for FLÄVIZ is now used to visualize the data (Lorenz WE et al. 2020). Within the application, shapes can simply be exchanged by replacing the 3DS files; this applies to both, the building volumes with their roofs and the terrain model (see Figure 5). Since all buildings are pre-manipulated in Grasshopper (or Rhino, respectively), there exists also the possibility of setting them on different layers. As a result, information can be added to single blocks separately in the Three.js model, including the estimated degree of attic extension and physical address. It also enables the assignment of messages that are entered by users. The additional attributes are the subject of future work.

CONCLUSION

In this paper, the authors presented a workflow to detect the degree of attic extensions. This workflow consists of 1) an interpretation of LOD2 data of the building stock, provided by the City of Vienna, 2) photogrammetric recordings of the roof areas with drones (as additional information and if no LOD2 model is available), and 3) thermographic recordings, again shot with drones. The workflow's aim is to provide a basis for a more in-depth study in the future. In the course of this study, two scripts were written in Grasshopper® (for Rhino®) to capture and interpret the data, and to translate photogrammetry data into LOD2 equivalents, respectively.

Due to population growth, mainly as a result of an influx from outside, there exists a constant need for additional living space in Vienna. This demand can be met either through inner densification or through new constructions in the periphery. The first case includes, among others, attic extensions. Many extensions that have already taken place have not been recorded, nor are the location of further potentials known (attics that can still be expanded). However, it is important for the city to know the potential in order to implement the necessary infrastructure or to provide target support.

The City of Vienna provides the whole building structure as LOD2 data. These data contain polygon networks from which roof surfaces can be extracted because of their unique color. The difficulty lies in the recognition of single buildings and in the translation of the 2-dimensional roof surfaces into 3-dimensional volumes that describe the attic. The authors developed a Grasshopper® script that provides an initial approach to translate LOD2 data into attic volume and that illustrates the difficulties encountered by such a translation. Despite some unsolved challenges, it could be shown that two parameters give a first indication of the degree of expansion: 1) the ratio between the actual volume and the maximum possible extension, and 2) the size of partial roof surfaces together with their vector normals. However, due to fuzziness (level of detail and inaccuracy in data interpretation), this initial assessment requires further consideration. The improvement of data, especially the level of detail of roof surfaces, can be achieved by photogrammetric recordings with drones. With this, the difficulty lies, on the one side, in the flight permission in densely populated areas and, on the other side, in the extraction of the roof surfaces. Concerning the latter, the algorithm used to interpret the LOD2 data can be applied with slight modifications. In both cases, surface normals and adjacencies recognize interconnected roof surfaces. In more detail, the script interprets the triangulated individual areas resulting from the point clouds. Although a first conclusion about the usage can be made due to the shape, including eg dormers, still uncertainty exists. Thermographic recordings with drones can improve this data. First investigations revealed that the usability of such data depends heavily on several factors: 1) the equipment available (including the resolution and the distance of the trajectory to the object), and 2) the day and time of year of the recording.

Future work concerns the improvement of the script for capturing the most accurate data possible from the LOD2 data and from the photogrammetric recordings respectively. Another aspect that will be looked at more closely concerns the thermographic recordings and how to transfer their result onto the model. The final information about attic extension will then be made available to the public via a webpage in order to be supplemented by reports coming from the population.

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