AN INTERACTIVE DESIGN TOOL FOR URBAN PLANNING USING THE SIZE OF THE LIVING SPACE AS UNIT OF MEASUREMENT

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ABSTRACT:

In urban planning, a common unit of measurement for population density is the number of households per hectare. However, the actual size of the households is seldom considered, neither in 2D nor in 3D. This paper proposes a method to calculate the average size of the household in existing urban areas from available open data and to use it as a design parameter for new urban development. The proposed unit of measurement includes outdoor and indoor spaces, the latter comprising both residential and non-residential spaces. As a test case, a to-be-planned neighbourhood in Amsterdam, called Sloterdijk One, was chosen. First, the sizes of "typical" households, as well as a series of KPIs, were computed in existing neighbourhoods of Amsterdam, based on their similarities with the envisioned Sloterdijk One plan. Successively, the resulting size of the household was used as a design parameter in a custom-made tool to generate semi-automatically several design proposals for Sloterdijk One. Additionally, each proposal can be exported as a CityGML model and visualised using web-based virtual globes, too. Significant differences among the resulting proposals based on this new unit of measurement were encountered, meaning that the average size of a household plays indeed a major role.

1. INTRODUCTION

In urban planning, one of the common units of measurement for urban population density is the number of households per hectare (Torrens and Alberti, 2000). However, the actual size of the household is seldom considered, neither in 2D nor in 3D. In this paper, the overall idea is to add the size of the households, and – more in general – the size of the typical "living space", to the urban design process. This indicator will be first estimated using (open) urban data, and then used as a quantitative design parameter for a new development area. Please note that the concept of living space is intended here to be comprehensive of indoor, outdoor, residential and non-residential spaces, and considers all the spatial elements inside of a neighbourhood, such as green areas, water, streets, pedestrian areas, bicycle lanes, parking lots, etc. As test case, the Haven-Stad project area in the city of Amsterdam, The Netherlands, was chosen because of its envisioned development plans: 70000 new households in the following 20 years are expected to be built. In particular, the second stage of the project, called "Sloterdijk One" and located in a western area of Amsterdam, was chosen due to its size (58 hectares) and the number of planned new households (11220) to be built. The approximate extent of the area is shown in Figure 1.

The work presented in this paper is structured in three successive steps. In the first step, the major goal was to describe and characterise quantitatively the current situation of a city (and its neighbourhoods) by computing a series of meaningful KPIs (Key Performance Indicators). Such KPIs, combined with professional experience in urban planning, can help the urbanists in "reading" and understanding the city, and eventually improve the quality in the design process of the built environment. This is indeed a

rather innovative approach, because knowledge (and quantitative design parameters) are directly extracted from existing urban contexts, choosing from "real-life" acknowledged examples of successful urban interventions as reference. In order to compute the KPIs, different spatial and non-spatial datasets were retrieved and harmonised. KPIs were computed to take into account aspects tied to land use, housing density, average price of households, the quality of life, the year of construction of the buildings, etc. Thanks to these KPIs, and having in mind the overall target goals and the regulations given by the Municipality of Amsterdam for Sloterdijk One (e.g. housing density: 192

Figure 1. The "Sloterdijk One" case study area, located in the western part of the city of Amsterdam, The Netherlands.

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households/ha, residential use: 80% of new construction spaces, social housing: 30% of households, quality of life: high), 6 similar existing neighbourhoods in Amsterdam were thus identified and selected.

In the second step, for each selected neighbourhood a number of additional parameters were computed to eventually obtain the size of the average "typical" living space in each neighbourhood. Such parameters consist of the average values for indoor spaces (calculated as volumes in 3D) and for open spaces (calculated as areas in 2D). Computation of indoor spaces was further specialised into residential and non-residential. LoD1 (Level of detail 1) building geometries were used for this purpose. First, non-residential spaces were computed, and then gross residential spaces were obtained as difference between the LoD1 volumes and the non-residential ones. A conceptually similar approach was followed to compute the outdoor spaces, though they were obtained as values of areas. Additionally, to facilitate the (visual) comparison of the results, all living-space values were normalised and referred to one prototypic average building – in our case, composed of three households, with additional non-residential and outdoor spaces.

Finally, in the third step, the sizes of the living spaces were used as parameters for the urban planning design phase. A prototype of a semi-automatic design tool was developed. The purpose is to speed up the design process and allow for the creation of many proposals in the same study area in a quick and interactive way. The user can set and vary several design parameters and, on the fly, a new design proposal is generated. At the same time, instantaneous feedback is given on whether certain design constraints are respected or not. Some parameters (and constraints) are in fact based on the guidelines of the Sloterdijk One project published in the "Sloterdijk I Strategie nota" by the Municipality of Amsterdam (2016). For transparency and communication purposes, a specific report, containing all design parameters, can also be generated for each design proposal. Additionally, each proposal can be exported in CityGML format (Kolbe, 2009). This allows to export and integrate 3D geometries and attribute data (and semantics), as this is indeed a rather well-known limitation of most CAD-based design tools. Another advantage of using CityGML consists in the availability of existing tools to visualise and publish each design proposal embedded in an existing city model (e.g. in Google Earth or CesiumJS). This can indeed contribute to and facilitate the participatory process.

1.1 Objectives and scope

Two are the main objectives of this work. As already mentioned, the first is to analyse the current situation of our cities through existing open data. The generated knowledge is intended to facilitate the way of reading the city for urban planners and propose a new unit of measurement in urban development projects. The second goal is to define a methodology to make research by design, allowing a practitioner to generate several design proposals in a quick way, based on the knowledge previously created. One known problem that this work aims at reducing is the long time in the decision-making regarding urban design process. Sometimes, these processes can last up to 10 years. During these years, the guidelines or design parameters of a project can change. Therefore, this tool could be additionally used in the following stages of the design process:

- **Before:** To help establish the minimum parameters of a new project.

- **During:** To review the guidelines and check whether the parameters are up to date.
- **After:** To adjust the parameters or add extra information to the analysis over time.

Finally, the tool is also intended to facilitate the participation of many stakeholders from different fields of expertise, as it allows the visualization and digitization of design proposals in a quick way. A process that nowadays is otherwise expensive and time consuming.

2. RELATED WORK

2.1 Computer-based design tools for urban planning

In recent years, several design tools were created to facilitate the work of urban planners. Some of these tools are fully automatic, generating design solutions without any intervention of designer. An example is the Interactive Urban Synthesis (König et al., 2017). Other tools are semi-automatic, allowing some interaction between the user and the software. These tools can be very powerful because they combine professional knowledge with the strength of computers. One of the most popular cases in Europe is the Kaisersrot project in Zurich, Switzerland (Kaisersrot project, 2001). In this project, the software used the needs of the future residents as primary input, together with information about the context, to determine a balance in needs and create an optimal parcellation solution. Furthermore, the user interacts with the software to create a road network based on the created plots. Another 2D tool is InViTo (Pensa and Masala, 2014) which focuses on large scale urban projects for analysis and design. Together with the Kaisersrot project, these are very powerful tools but the 3D element is missing in the analysis. Another tool was proposed and developed by Beirão (2012) in his PhD thesis and is called CItyMaker. It works in 3D and contains a strong background of induction patterns for urban design. The tool is mainly focused on urban fabrics design allowing spatial analysis, but leaving partially uncovered the morphology of buildings. The Möbius modeller (Janssen et al., 2016) is a web-based parametric modelling tool aimed to run geo-computational procedures in a 3D environment. It can be compared with the Grasshopper tool for Rhino taking advantage of the possibility to combine geometric data with some semantic information. Its limitation however lies in the rather limited interaction between the 3D model and the user during the model generation process.

2.2 City analyses based on open data

One of the recent projects in urban morphology analysis is the work of Kepczynska-Walczak and Pietrzak (2017), in which the city of Lodz is analysed in 3D enabling comparisons among different areas within the city. This is a new way of analysing the current situation of a city based on data, enabling the understanding of the complexity of the urban environment.

2.3 Road modelling

In urban planning, the road design is the backbone of the open space quality. Around the world, governments and municipalities have made available several interactive tools to create street cross sections. For example, the Abu Dhabi Urban Street Utility Design Tool (USDM, 2019), Streetplan (Streetplan, 2019) or Streetmix (Streetmix, 2019). These online tools are available to everyone but in the best-case scenario the user can export an image of the design or just basic information of the realised work. Another tool related with road modelling is the work of de Klerk

and Beirão (2017), in which a method to create street cross sections was implemented in Rhinoceros and Grasshopper with a complex background of urban rules. Unfortunately, all these tools are working only in 2D and do not take into account the complete network but only punctual elements in the transport network.

2.4 Size of the living space

The size of the living space is nowadays studied from different perspectives, e.g. in terms of quality of life, health or space efficiency. Regarding quality of life in residential areas, a direct correlation between the size of spaces and quality of life (i.e. bigger spaces correspond to higher quality of life), however, this holds true only in some cases. In the Netherlands, Maas et al. (2016) show that quality of life is actually more directly correlated to the "greenness" in the neighbourhood, healthier its inhabitants, or happier according to White et al. (2012) in the UK. Regarding indoor spaces, the size of the households is also an indicator of good quality of life. According to Foye (2017), in the UK, bigger houses can increase the level of subjective well-being, but only for a short period of time. Related to space efficiency, The Why Factory group at TU Delft carried out a design research project called On-The-Go (The Why Factory, 2018), in which the size of the living space is estimated by measuring the minimum space needed for daily activities like cooking or sleeping.

3. METHODOLOGY

This work is divided in 3 successive steps. The first one describes and characterises quantitatively the current situation of Amsterdam (and its neighbourhoods) by computing a series of meaningful KPIs. A selection was made on a limited number of neighbourhoods best approximating the desired characteristics of the new development area in Sloterdijk One. In the second one, different calculation methods were defined and implemented for each selected neighbourhood in order to extract a number of parameters and eventually compute the size of the typical living space in each neighbourhood. Finally, in the third step, the different sizes of the living spaces previously obtained were used as design parameters in the developed design tool (Figure 2).
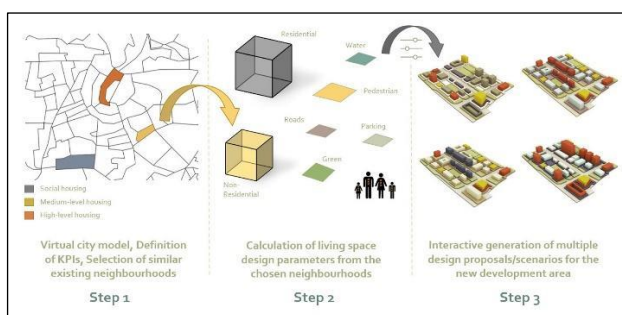

Figure 2. Overview of the proposed methodology.

3.1 Step 1: Selection of similar existing neighbourhoods

Sloterdijk One is only comprehensive of one neighbourhood (*buurt,* in Dutch). In this work, the *buurt* was used as unit for spatial analyses. In order to find neighbourhoods matching the development targets of Sloterdijk One, datasets were collected to investigate the following aspects:

- Land use,
- Housing density,
- Price of the households,
- Quality of life,
- Year of construction of the buildings.

The datasets were selected because of their relevance in relation to the Sloterdijk One requirements. The land use is a fundamental element to find predominantly residential neighbourhoods. The housing density is important because the desired density for Sloterdijk One is 192 households/ha, close to the highest in Amsterdam (235 households/ha). The household price was used as a reference to classify the socio-economic status of the neighbourhoods in social, medium-level or high-level classes. In the Sloterdijk One guidelines, it is requested to distribute new dwellings as follows:

- Social housing (30%),
- Medium-level housing (40%),
- High level housing (30%).

The criteria to apply to determine a socio-economic status to the neighbourhoods are:

- Social housing: below 5000 €/m^2,
- Medium-level housing: between 5000 and 6000 €/m^2,
- High level housing: above 6000 €/m^2.

As the Haven-Stad project is aiming to replicate the highest quality of life already present in the city, the "Leefbaarometer dataset" was used as a reference to quantify the liveability in a neighbourhood (details in section 4.1). This dataset is meant to provide information about "the extent to which the living environment meets the conditions and needs that are imposed on it by people". Finally, the year of construction of the buildings is used in order to have a descriptor of the average "age" of the neighbourhood. i.e. to understand whether the area is a recent development or a historical part of the city.

3.2 Step 2: Living space calculation

Based on the results from the previous step, the best candidate neighbourhoods were selected to be analysed. The space calculation method was divided in two main categories: indoor space (calculated in 3D from LoD1 building geometries) and open space (calculated in 2D). All the calculations were carried out using as a reference one single "typical" household. In Figure 3, an overview is given of the classes taken into consideration for space calculation.
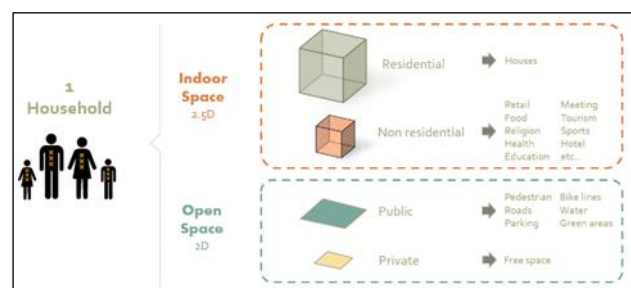

Figure 3. Elements to consider in space calculations.

The gross volume of all buildings in each neighbourhood was used to compute the indoor space, which was further specialised into residential (RESID) and non-residential (NR) space. Please note that in this work volumes are intended as *gross* volumes. For this reason, LoD1 building geometries were used to calculate the volume of indoor space. NR spaces were first computed, then RESID spaces were obtained as difference between the LoD1

volumes and the NR ones. An example is given in Figure 4. The resulting residential space was then divided by the number of households in the neighbourhood to calculate the average size of a "typical" household for that neighbourhood. The same procedure was used for non-residential spaces to calculate the amount of NR space per household. Additionally, the NR space was divided by the number of working people in the neighbourhood to calculate the average size of a working space. When it comes to the open spaces, the areas were first classified in private and public. The latter were further subdivided into: roads, green, parking, bike lanes, water and pedestrian lanes. Similarly to the indoor spaces, all open spaces were then normalised with regard to one single "typical" household.

Figure 4. Example of indoor space calculation in Fannius Scholtenbuurt, Amsterdam. Transparent volumes: LoD1 buildings, coloured volumes: non-residential spaces (the colour coding corresponds to the type of space).

3.3 Step 3: Generation of multiple design scenarios

The previously obtained space parameters were used as a reference in a developed software prototype tool to create fast, GUI-based and interactive design proposals for urban development projects. The basic idea consists in multiplying the size of the living space by the amount of desired households and, at the same time, in adapting the rest of the functions based on the municipality guidelines. The municipality guidelines of the Haven-Stad project were formalised and introduced in the design tool as parameters, or constraints. They can be found in the "Ontwikkelstrategie Haven-Stad" document (Municipality of Amsterdam, 2017). Figure 5 contains an excerpt of such parameters. Finally, some additional design parameters, commonly used in urban planning, were also added to the tool (e.g. Floor Space Index (FSI), Ground Space Index (GSI), total amount of m^2 of construction, the building heights, etc.). Some of these parameters can be set by the user, others are calculated on-the-fly. If certain constraints are not respected, a warning message is issued to inform the user.

		Now	Future
≋	m2	360.311	1.122.000
👫	jobs	4.731	7.480
⌂	households	ø	11.220
🎓	schools	ø	8
♥	hospitals	ø	8
🏃	m2 sport	ø	56.100

Figure 5. Overview of (some) goals envisioned for Sloterdijk One by year 2040

In the tool, it is possible both to preserve existing buildings and to create new buildings. The latter are generated based on a

parcellation plan of the area provided as input by the user. Their footprint depends, on the one hand, on the shape of the parcels and, on the other hand, on a library consisting (for now) of two typologies: solid shape or courtyard shape. In the case of courtyard building, the thickness of the building is an additional design parameter (Figure 6). The new buildings can be residential, non-residential or mixed-used. Regarding the open spaces, the user must only provide the road infrastructure as single centrelines to perform the open space calculations. In the tool, it is possible to have different roads typologies. For each of them, the amount of water, green, roads, parking, bike and pedestrian spaces is obtained consequently.

One design simplification consists in considering the road intersections just as roads space. The effective space of calculation for the six functions takes place in the remaining road sections (Figure 7). For comparison purposes, all resulting spaces (indoor and outdoor) are normalised with regard to a single building. A graphical layout, as shown in Figure 8, is therefore obtained for each neighbourhood.
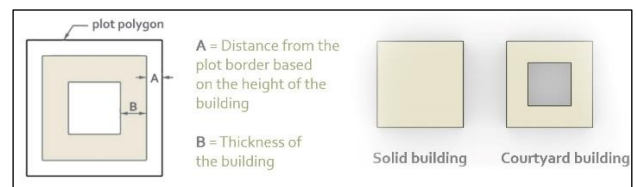

Figure 6. [Left] Example of design parameters for courtyard buildings. [Right] Available typologies for (new) buildings.
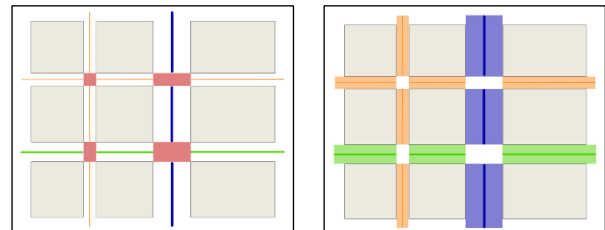

Figure 7. [Left] In red: intersections considered as car traffic space. [Right] In orange, green and blue the effective space for calculations. The colour indicates the typology of the roads.
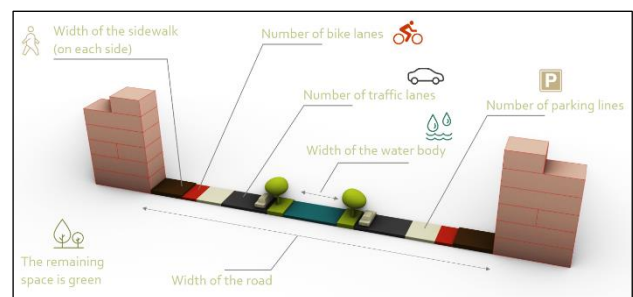

Figure 8. Section of possible layout for outdoor spaces. Please note, the trees are actually not modelled in the scenarios, they are added to the 3D section model, as shown here.

4. IMPLEMENTATION

4.1 Data sources

In this work, the following datasets were used. Unlike differently indicated, they can be accessed and downloaded either from the

Amsterdam WebGIS (Municipality of Amsterdam, 2019a), or via the Dutch portal for open data (PDOK, 2019):

- *Basisregistratie Grootschalige Topografie (BGT)*. Dataset containing several topographical layers. Some were selected and used to compute the 6 categories of existing open spaces.
- *Basisregistratie Kadaster (BRK)*. Dataset containing all cadastral parcels and public spaces. This dataset was used to separate private and public space, i.e. if a parcel contains at least one building, it was considered as a private plot, otherwise, it was considered public space.
- *Gebied in beeld*. Dataset containing the number of working people per neighbourhood (Municipality of Amsterdam, 2019b).
- *Grondgebruik 2017*. Land use dataset used to identify predominantly residential neighbourhoods.
- *CBS Wijken en Buurten 2017*. Official Dutch dataset containing the information related to the census of the Netherlands. This dataset was used to compute a KPI called Average Neighbourhood Density Index (ANDI) and expressed as (number of households)/(neighbourhood area in ha). Of particular interest were those neighbourhoods with an ANDI higher than 95 households/ha.
- *Woningwaarde 2015*. Dataset representing the average price of households. It consists of polygons corresponding to ranges of price. By means of spatial overlay between these and the neighbourhood polygons, a KPI named Average Neighbourhood Price Index (ANPI) was computed as area-based weighted average of the prices within each neighbourhood.
- *Functiekaart*. Dataset containing all the non-residential activities in the city. A very approximate indication of the non-residential surface (in m^2) is also given, but preliminary tests showed that this quantitative information could not be used effectively. Therefore, for the estimation of the non-residential surfaces (and volumes) a set of assumptions was made, based on empirical considerations, personal experience, and some *in situ* visits: an average height of 4 m for each non-residential storey is assumed, as well as a specific (maximum) number of storeys for each activity, in case that activity is found in a building. In Table 1, an example of the assigned building storeys per activity are given.
- *Leefbaarometer* (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2019). A Dutch dataset containing a "Quality of life"-index, used for the KPI Quality of life (QOL).
- *Bouwjaar*. Dataset containing the year of construction of the buildings in Amsterdam. It was used to compute the KPI called Average Neighbourhood Year Index (ANYI).

Function	Storeys
Internet shop	1
Bicycle rentals	1
Café – Diner pub	1
Child care (independently)	2
Coffee shop	1
Elementary school	ALL
Fitness - Gym - Yoga space	2
Hotel – Lodging	ALL
Secondary education	ALL
Supermarket (large)	ALL
Theatre – Music stage – Events hall	ALL

Table 1. Number of (maximum) storeys for each non-residential category in a building. "ALL" means the total height of the building containing such activity.

- *Actueel Hoogtebestand Nederland 3 (AHN3)*. Lidar-based classified point cloud, available for the whole Netherlands. The point cloud was used, together with the footprints of the buildings, to generate the LoD1 geometries. Analogously to existing tools like 3Dfier (TU Delft 3D Geoinformation, 2019), the median height of the roof points was used to approximate the horizontal roof geometries. However, an additional assumption was made with regard to the LoD1 geometry: following (also) several visits *in situ*, it was decided to add a 4-m-deep cellar to each building, to be used either as storage or as garages.

4.2 3D modelling tool

The software Rhinoceros (Rhino) was used to build the 3D modelling tool. Grasshopper (GH) was used as graphical algorithm editor upon which to develop the tool for parametric modelling. Existing Grasshopper nodes were used and linked to newly, *ad hoc* developed ones based on Python. The user is requested to provide as input three datasets: 1) the road centrelines, 2) the polygons of the plots and 3) the 3D geometries of the existing buildings to be maintained.

The tool is mainly based on two elements: the overall Graphical User Interface is based on Rhino, while the actual geometry-computation and generation is based on GH. The latter is accessible by colour-coded panels: the yellow ones provide real-time information to the user, while the grey ones allow to edit the design parameters (Figure 9). The parametric modelling process is guided by design rules, warnings or suggestions that guarantee the minimum space quality standards in the project. An example is shown in Figure 10. Some of the implemented constraints are:

- Warning about reaching the maximum height of the buildings,
- The distance between buildings, calculated based on the height of the buildings,
- The selection of the plots depending on their area. This is intended to guide the user in the selection of the plots for solid and courtyard buildings.

During the interactive modelling phase, the tool also provides additional information on the surroundings in the form of 2D and 3D maps to help the user in the design process (Figure 11). For example, all buildings around the neighbourhood within 1.5 km distance, the non-residential functions in the same radius, the public transportation network and a topographic map are loaded and shown. These datasets are partly the same mentioned before, otherwise were collected from the PDOK geoportal or the Amsterdam WebGIS. Further details about the implementation and the functionalities of the tool can be found in (García González, 2019). A demonstration video can be visualised at this link: https://www.youtube.com/watch?v=cPYT5_cFIgw.

Figure 9. Example of the Graphical Interface of the tool. [Left] 3D visualization in the Rhinoceros viewport. [Right] Grasshopper window with info panels and data nodes.
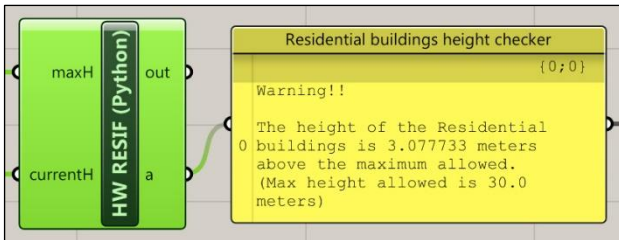
Figure 10. Example of warning issued by the tool to inform the user that the building height is exceeding the limit allowed.

Figure 11. Example of visualisation of additional contextual information during the design process.

Figure 12. Visualization in CesiumJS of a scenario. Specific attributes can be retrieved by clicking the corresponding building or road element.

All datasets are available directly in Rhinoceros as "layers" that can be enabled and disabled when needed. Each layer is pre-processed before being loaded. It is important that all data share the same coordinate system (e.g. EPSG:28992).

The tool generates different types of outputs for each generated scenario (3D model). They are summarized in the following:

1) Screenshots can be generated on-the-fly for each scenario, during any moment of the process;
2) Once a scenario is obtained, a report containing all design parameters, KPIs and constraints can be generated and exported. This is intended for transparency and communication purposes;
3) Each scenario is exported from Rhino as DWG format (Geometry + IDs) and CSV format (attributes + IDs). In order to integrate geometry and attributes in a single coherent model, some workbenches in Safe Software's FME 2019 were developed and linked to generate a CityGML model. Each CityGML file can be further imported, for example, in the 3DCityDB, or be additionally converted and visualised in web-based virtual globes such as Google Earth or Cesium JS.

This is meant to facilitate the dissemination and visual comparison of the different scenarios, and for potential involvement of a wider audience in the evaluation or participatory process. An example is given in Figure 12.

5. RESULTS AND ANALYSIS

5.1 Selection of most similar neighbourhoods

Based on the generated KPI's, queries were defined to select the candidate neighbourhoods to be further analysed. Six neighbourhoods were eventually extracted based on their similarity with Sloterdijk One. Their location in Amsterdam is shown in Figure 13, while Table 2 contains some KPIs.

Neighbourhood	Density (househ./ha)	Price €/m²	QoL	ANYI
Java-Eiland	97	4885	8	1996
Elandsgracht.	151	6738	9	1593
Orteliusbuurt	203	5442	4	1931
Lootsbuurt	214	6422	7	1918
Hercules Seghersbuurt	221	6207	7	1920
Fannius Scholtenbuurt	235	6151	4	1930

Table 2. Some characteristics of the 6 selected reference neighbourhoods.
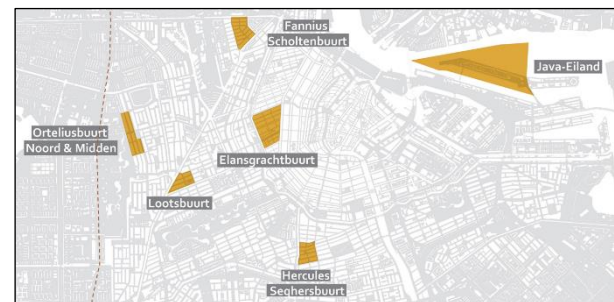

Figure 13. Selected reference neighbourhoods in Amsterdam.

5.2 Space calculation

For each neighbourhood, all living-space values were first normalised and referred to one prototypic average building (in our case, composed of 3 households, with additional non-residential and outdoor spaces) to facilitate comparison in a visual and easily human-readable way: the non-residential space is located in the lower storeys and residential households above it. The open spaces are located in front of the facade. An example is given in Figure 14 representing the Elandsgrachtbuurt and Orteliusbuurt in Amsterdam. Further comparative analyses can be found in (García González, 2019).

Figure 14. Example of two prototypic buildings used for comparison. Each building represents the living-space values of the corresponding neighbourhood (e.g. Elandsgrachtbuurt and Orteliusbuurt).

5.3 Creation and comparison of scenarios

Several design proposals were created to test the tool. In order to understand the role of the household size in urban development, two designs proposals were selected, i.e. those obtained starting from the living-space parameters computed for the Elandsgrachtbuurt and Orteliusbuurt neighbourhoods. These two cases differ in terms of working space and residential space sizes. Elandsgrachtbuurt is one of the most expensive areas in Amsterdam, the spaces are larger and it lies in the historic part of the city. On the other hand, Orteliusbuurt is far away from the centre, part of the modernist expansion of the city with small residential spaces and less services.

The modelling process was carried out using exactly the same constraints and design parameters for both proposals: 11220 new households, around 8000 working places and the same buildings for each category, the only difference being the size of the households and the size of the working places. The Orteliusbuurt model contains more than 12000 working places because the non-residential buildings must have at least 1 storey (the minimum available in the tool), so, this is the minimum number of working places for this configuration. In Figure 15, the 3D models of both scenarios are presented.

Sloterdijk One goal: 11220 new households	Scenario (source: Elandsgrachtbuurt)	Scenario (source: Orteliusbuurt)
Household size (m^3)	440	285
Working space (m^3)	185	65
Working places	7524	12703
FSI	5.51	3.57
Construction area (m^2)	1754700	1136400
Storeys, residential	13	9
Storeys, mixed-use	15	10

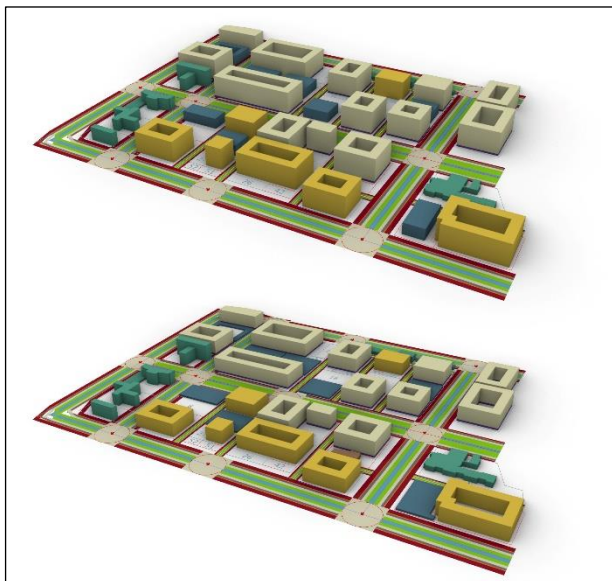Table 3. Comparison of data extracted from the logs of both scenarios.

Figure 15. [Top] 3D model generated in Sloterdijk One using the Elandsgrachbuurt space sizes as reference. [Bottom] The same model generated using the Orteliusbuurt space sizes.

The differences between the two scenarios are easily recognisable also visually. Nevertheless, an excerpt of the two reports is presented in Table 3. Comparison of data extracted from the logs of both scenarios. One can easily see that both scenarios can host the same number of households with very different characteristics regarding indoor spaces. This is a demonstration of the role of the size of the living space plays in urban development projects.

6. CONCLUSIONS

This paper has presented a methodology to introduce the size of the living space as unit of measurement for urban planning projects. The main idea is inspired by one of the ambitions of the Municipality of Amsterdam: analyse areas of 'urban success' in the city centre and reproduce them in the future expansion areas outside of the city centre.

In this work, the city *of the present* is analysed and characterised using existing (open) spatial and non-spatial datasets of the city itself. Knowledge resulting from these analyses is then transferred to design the city *of the future*. This approach is indeed a rather new way to think about the city of the future. However, its novelty requires a tighter coupling of the geomatics and urban planning disciplines, as a sort of "round trip" one can imagine starting from the typical domain of "Geo" (spatial data analyses), moving then to the more "urban planning" one (design and parametric modelling), and finally closing the circle and going back to the "Geo" domain (CityGML, Spatial DBMS, etc.).

A prototype tool for the interactive and semi-automatic design of new development areas was implemented and tested with a real-world case study located in Amsterdam. Despite its initial and prototypic nature, it already allows to define design parameters and constraints based on the GIS-analyses mentioned before, and to generate different possible design proposals (also called scenarios) that fulfil certain or only a subset of criteria. The user is informed throughout the design process whenever a certain constraint is not met. Several export possibilities are offered, in order to make the design process more transparent and public.

The information provided by each of these exports is aimed to help users in the different stages of the design process to set up, review or update the guidelines of housing development projects. Despite the need to introduce some simplifications and assumptions in the design model, the tool has contributed to demonstrating that the size of the living space, in particular the size of the household, can play a major role in the shaping of urban developments. It has been shown that defining just the number of new households in the same area is not enough, as rather different scenarios can be generated.

An "official", already existing, semantic 3D city model, which contains also detailed and reliable information about the spaces (volumes) of the buildings used for different purposes might indeed contribute to greatly speeding up the whole process, reducing the number of assumptions (and therefore raising the overall accuracy) and – globally – enhancing the quality of the results. Despite the fact that such a semantic 3D city model may not be available yet, it is indeed imaginable that it will be in the coming future, given the current trends in data generation, harmonisation and standardization. Hence, new possibilities will appear for urban planning-related "smart" applications.

Other elements widely researched when designing the city of the future are: cross section modelling for roads, the shape of the buildings and the spatial analysis of the current situation with GIS tools. For each of these three topics, several scientific documents can be found as a reference but it is rare to find these topics combined in a single research. This is the reason why in this work

all these topics were combined to start understanding their mutual relations.

In everyday practice, most of the design proposals often ends up "forgotten" or locally stored somewhere and, eventually, become inaccessible or lost. In this paper, the use of a standard formats like CityGML to store the generated design proposals might help to share the work of designers. The possibility to easily reuse or publish the results in web-based digital globes can contribute to the welcome beneficial "side effect" of further valorising the use of (open) datasets for design purposes, not to mention the advantages tied to the chance of using each generated model as input for further domain-specific analyses (e.g. solar irradiance, 3D noise and micro-climate simulations, urban heat island assessment, etc.)

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