DEVELOPMENT OF AN INTERACTIVE WEB GIS APPLICATION TO SIMULATE HOUSING POTENTIAL AND DEMAND

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ABSTRACT:

On 22.06.2021 the new law i.e., "Gesetz zur Mobilisierung von Bauland" (Baulandmobilisierungsgesetz) entered into force in Germany, enabling municipalities to give priority to building on inner-city open spaces at a higher building density. Especially for rural communities, where there are many underutilized properties and inner-city open spaces, there is great potential for redensification, which is addressed by the new legislation. Depending on the attractiveness of urban areas, many of the surrounding rural communities will experience an influx of population in the coming decades. The goal of this research work is to develop an interactive Web GIS application showing the housing potential and demand according to socio-demographic scenario for such a rural community. This application serves as a decision support system for the stakeholders i.e., the urban planning department of the municipality to re-densify the urban structure in a sustainable way. This work helps to build up a comprehensive geodatabase including all relevant physical, ecological, economic, and social aspects, which further locates and quantifies the potential open spaces and buildings gaps being suitable for redevelopment. Here, the housing potentials are divided into different constructional realization categories, which can be used for a realistic urban planning. The analyzed and calculated results will be visualized in a Web GIS application where the user is able to query and edit on different urban development scenarios.

1. INTRODUCTION

1.1. Background

Urban structure and urban sprawl are mainly based on population inflow and outflow. The main driving force was and is, along with other soft factors, the economic attraction through the offer of jobs. As the economy is undergoing a major change from industrial production to the tertiary and quaternary sector, the urban structures are changing rapidly in the last decades. Not only the presence of future-proof companies but also the educational infrastructure like universities and colleges and a high recreational value of a region, serve as pull-factors for the cities and regions and attract young well educated professionals and students.

In Germany, many of the up-coming cities are located in the south, especially in the state of Baden-Württemberg. The most important indicators for the population migration are the unemployment rate, cost of living, social security concerning the salary and the real estate market, which is closely related to new construction demand prognosis (BBSR, 2012). Therefore, urban planning strategies are needed in these up-coming regions and cities to plan for the increasing demand for housing in a sustainable way.

To meet the demand for residential housing the focus lies in re-densification of potential built-up areas in urban and rural regions. Brownfields such as old industrial and infrastructure sites represent huge potential after the disposal of contamination. However, there are not only large sites but also smaller ones resulting either from oversized and underutilized plots, from the demolition of buildings or, as is often seen in rural areas, from building gaps due to land speculation or family storage. A great potential lies in the designated areas of the building land adjacent to the inner area of the settlements located on the green field. The construction of these areas often leads to conflicts of interest with nature conservation and, as a consequence, to compensatory measures under nature conservation law, for which the municipalities have to pay.

There are specific legal requirements in the German Federal Building Code (Baugesetzbuch BauGB) for all of these potential residential development areas mentioned, whether large or small-scale. To meet future housing demand a new law was passed in Germany (Building Land Mobilization Act - Baulandmobilisierungsgesetz) on 23.6.2021, allowing the municipalities to prioritize inner city open spaces for higher urban density development (Bundesministerium des Innern, für Bau und Heimat, 2021). According to this law, the municipality can act as the initial purchaser to develop the vacant land for further residential development. To support this urban planning process, an interactive Web GIS Application was developed to simulate housing potential and demand. The application can help the stakeholders, e.g., the urban planning department, to visualize housing potential according to time-dependent availability and sociodemographic aspects in order to meet the increased housing demand.

In the pilot phase, the Web GIS Application was developed and tested in the study area of a rural district of the city of Ulm, located in the state of Baden-Württemberg, called "Eggingen", see Figure 1.

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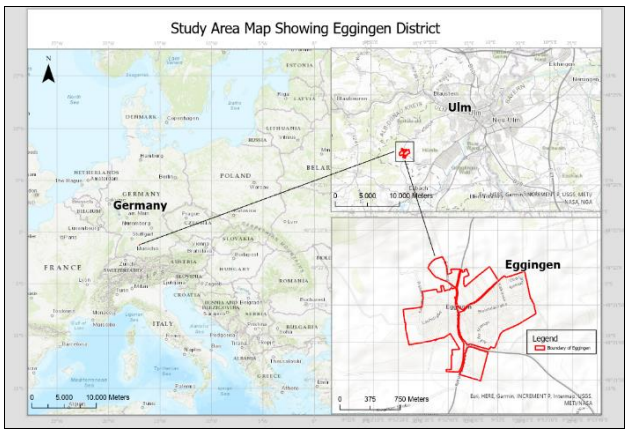

Figure 1 : Study Area

1.2. Urban Planning Regulations

The comprehensive German Federal Building Code (Baugesetzbuch, BauGB) regulates urban land use planning in details. A distinction is made between the so-called preparatory land use planning and the binding one (Söfker, 2021). For the Web GIS Application, both plans were examined and presented. On the one hand, the preparatory land use plan (Flächennutzungsplan) shows the potential marginal green field sites and the representation of the permitted type of use, see Figure 2.

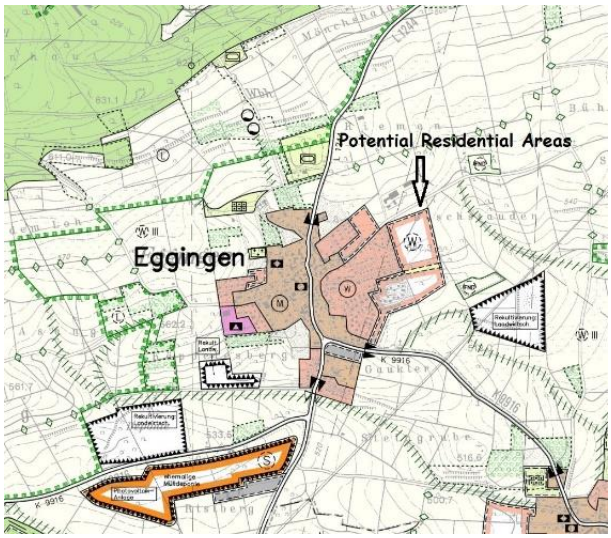

Figure 2 : Land Use Plan of Eggingen District

On the other hand, the binding land use plan (Bebauungsplan) specify not only the type of use (see Figure. 3), but also the degree of building use, from which the potential floor areas of each residential building can be calculated.

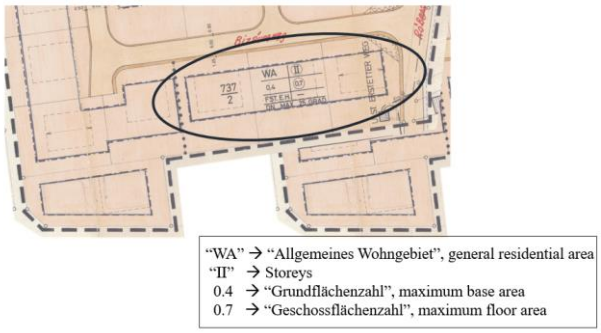

Figure 3 : Binding Plan of Eggingen District

In addition, the BauGB contains regulations for the admissibility of construction projects according to the current status of the binding land use plan. For older village centers in rural regions §34 of the BauGB is decisive. This paragraph stipulates that the new building project must fit into the built environment in terms of the type and degree of building use. For the pilot area, eleven zones were defined by experts, specifying the average type and degree for new building projects, see Figure 4. To check the plausibility of the delineated zones, further data on the historical development of the district of Eggingen from the State Office for Environment (Landesanstalt für Umwelt, LUBW) were evaluated.

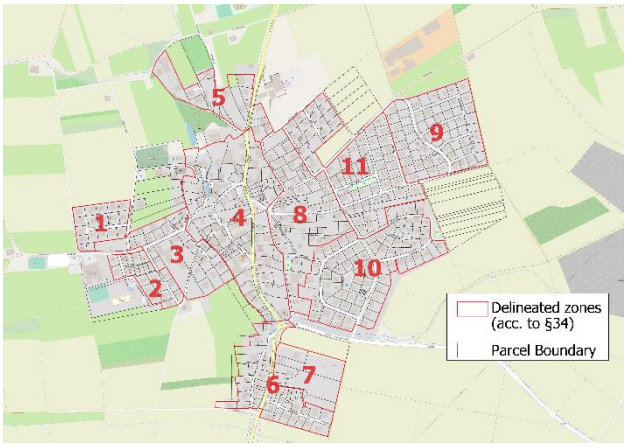

Figure 4 : Zone Delineation of Eggingen District

The newly passed Building Land Mobilization Act enable municipalities to define partial building plans which replace the existing binding plans as well as the specifications of §34 BauGB according to a higher degree of building use and social housing promotion. The following simulation of housing potential is based on the specifications of all existing plans and legal regulations, either preparatory or binding about the type and degree of building use. Due to legal feasibility, the simulation approach also differentiates between short term, mid term and long term availability of housing potential. Therefore, the developed Web GIS Application on one side helps the municipality to analyze the already existing housing potential and on the other side to target the future housing need.

2. METHODOLOGY

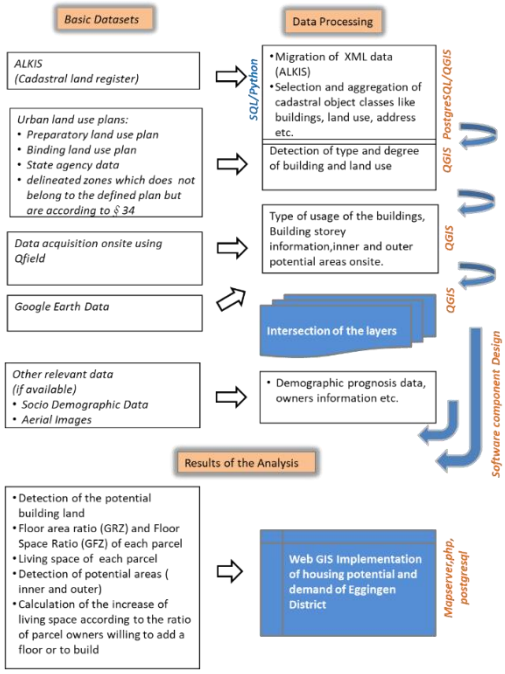

Figure 5 : Methodology

2.1. Basic datasets

Official and cadastral data (ALKIS) is the main data source in the project. ALKIS, implemented in Germany since 2015, merges and integrates data of the former cadastral map together with the former property registry. In ALKIS, spatial and non-spatial related data were systematically stored together without redundancy. The Working Committee of the Surveying Authorities of the States of the Federal Republic of Germany (AdV) has developed a technical concept for the management of all official geodata (AdV, 2009). ALKIS data is provided by the municipalities as a NAS-format, which is based on Extensible Markup Language (XML), Geography Markup Language (GML) and Web Feature Service (WFS). It either can be imported directly to the PostgreSQL database using norGIS ALKIS import software as PostGIS layers (norBit Development Team, 2022) or can be opened in QGIS software by adding a vector dataset.

Preparatory land use plan data has been utilized to delineate the inner and outer area of Eggingen city district. Binding land use plan has been utilized to determine the Floor Area Ratio or Grundflächenzahl (GRZ), Floor Space Ratio or Geschossflächenzahl (GFZ), storey and the type of the building (Art). Approximately 25 georeferenced images including the planning right information provided in text format have been used as a data source. Each image provides the individual land information, whereas the regulation and area information is conveyed by the texts as illustrated in Figure 3.
Baden Württemberg agency for the environment (LUBW) provided the information regarding the age of the individual buildings and the land use in the study area. This information has also been deemed for further analysis.

Furthermore, field data acquisition through surveys concerning land usage category, potential building land for development, building's type, storey information and condition and pictures were collected using four tablets, which were then compiled into a single database for additional analysis in QGIS (Ostadabbas et al., 2020).

Among the other relevant data, sources include sociodemographic data, which was provided by the municipality of Ulm. This data comprises the household information, age structures, owner information and population forecast. The demographic prognosis data consists of the age specific population prognosis since 2015 and a simulation till 2031. Additionally, the municipality also provided aerial photos of the whole Eggingen city district, which presents further insights regarding the type and usage of the land. The 3D building data from Google Earth has also been utilized for reviewing the storey information of the buildings.

2.2. Data Processing and Analysis

The ALKIS data has been migrated from XML to shapefiles and stored in the database. Among the various information contained in ALKIS data, specific cadastral object classes like buildings, land uses, address, owner information etc. have been used for further analysis. Preparatory and binding land use plans assists in the detection of type and degree of buildings and land use. As per the data from Baden Württemberg agency for the environment, measurements and nature conservations, the study area has been delineated into three specific categories determining the age of the buildings in the study area i.e., the buildings built on 1930, between 1930-1966 and 1998-2004. These categories of the delineated zones, which is not included in the defined plan according to §34, aids in the detection of degrees and type of buildings. In conjunction with the above mentioned plans, the surveyed data have been assigned to individual buildings as information regarding storey, usage type etc. Collating all these information the cadaster land map has been created. Subsequently, the critical parameters to define the potential building lands have been established in the following segments.

Floor Area Ratio (GRZ) refers the ratio of the area of each building in their respective land in square meters. Therefore, GRZ is calculated as:

Floor Area Ratio = Area of Buildings / Area of respective Land with a surcharge of 5% for footpaths, garage paths, small streets etc. *(1)*

For the lands having the GRZ information mentioned in the binding plan, it has been directly retrieved from the plan. Alternatively, the lands for which the binding plan or the GRZ information is unavailable, those have been assigned the average of the surrounding GRZ (according to §34BauGB) based on the delineated zones as mentioned in Figure 4.

As mentioned in previous section 2.1, the storey information has been collected from survey and Google Earth. Each building has been monitored individually and the storey information has been collected as per the current situation. As an important part of requirement analysis, storeys have been given specific codes by the stakeholders for further computation procedures. Similar to GRZ, storey information is also retrieved from binding plan. Alternatively, for the lands having no binding plans or missing storey information, it has been calculated based on the average of the surrounding lands in the same zone.

The Floor Space Ratio (GFZ) refers to the areas of residential buildings. Garages, gardens, farm buildings and commercial buildings are not taken into consideration for further calculations. Firstly, the areas of the main buildings and respective lands have been calculated. Subsequently, the GFZ is calculated as:

*Floor Space Ratio = Floor Area Ratio of main buildings * Storey of the main buildings* (2)

Apart from the critical parameters mentioned above, the data from the onsite survey and municipality regarding the development of potential building land have been considered. The potential building land has been categorized according to the type and availability for further development.

i. Short Term Availability: This refers to the lands, which are immediately available for development by the municipality. These includes the following categories:

- Building Gaps: There are total 13 building gaps in Eggingen district among which 2 lands are in the mixed building area and 11 lands are in residential area. The areas of the lands are not more than 2000 m².
- Building Application: This category refers to the lands for which building application has been submitted officially. 4 lands have the approved building application where immediate development can be started.

ii. Mid Term Availability: This refers to the lands which are available in two to five years for the development by the municipality.

- Underutilized Land: There are total 5 lands which have not been used as per its capacity. All these lands are in mixed building areas. The buildings in these lands have the potential to increase the number of storeys. These lands come under the inner potential city development. The areas of the lands are more than 2000 m².
- Outer Potential Area with Planning Right (Binding Plan): There is binding plan on 11 lands in the outer area, situated in the eastern part of the city. Since this is a potential area, therefore they have proper development plans (see Figure 2).
- Built Up Areas: These areas refer to the lands in residential and mixed building areas but do not come under the other potential categories. Among these lands, most have existing buildings with a potentiality to develop more storeys.

iii. Long Term Availability: These refer to the lands, which will require a longer time, approximately a decade, for development by the municipality.

- Outer Potential Area with Land Use Plan: These lands are situated in the outer areas of the city as per the preparatory land use plan but have the potentiality for further housing development. Following figure shows the final output of the analysis.

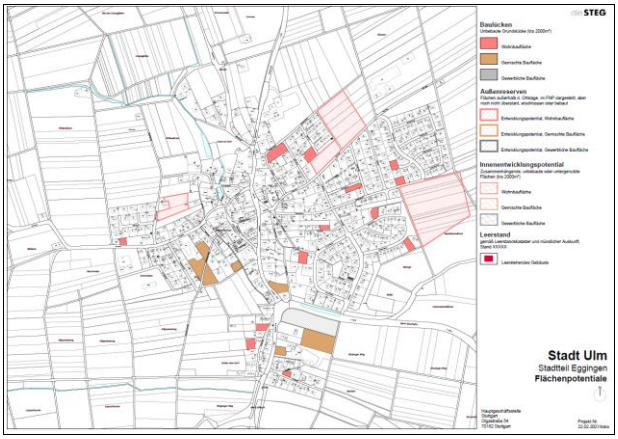

Figure 6 : Locations of the Potential Lands in Eggingen District, Source: die STEG GmbH

Figure 6 shows the current location of the potential building lands. All the potential building lands have been classified into three major categories- building gaps (Baulücken), outer potential (Außenreserven) and inner potential area (Innentwicklungspotential). These categories have been sub categorized into residential area (Wohnbaufläche), mixed area (Gemischte Baufläche) and industrial area (Gewerbliche Baufläche).

2.3. Software Component Design

As mentioned in previous sections the study aims to develop a Web GIS Application, which facilitates the analysis and simulation of the housing potential demand. Thus, selection of web components has played a crucial role. While this can be a complex and challenging process, there are a couple of basic preferences to be made. To set up a web server based on windows operating system, the opensource Mapserver has been installed. Afterwards, Leaflet (leaflet Development Team, 2021) framework was configured and connected with it. All the data in shapefile format had to be transformed in mapfile to connect with Mapserver (MapServer Development Team, 2021). Each layer has been prepared with the respective styling, colors, texts, formats, projection, and queries in the mapfile, which then directly connected to PostgreSQL database.

Figure 7 depicts the workflow of the development phase of the Web GIS Application. In the subsequent section, the working principles and the connectivity of the different components are described.

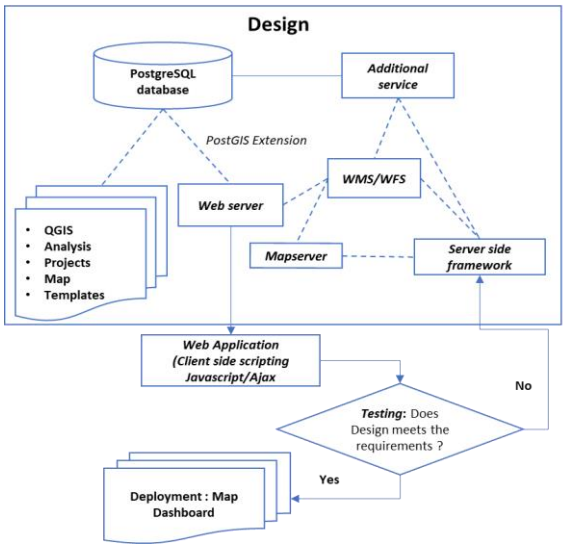

Figure 7 : Web GIS Application Design Workflow

2.3.1 Development of Web GIS Application

The calculated layers stored in the PostgreSQL database have been implemented in Mapserver as a Web Map Service (WMS) both statically as well as dynamically. The static layers show the basic features such as plots, buildings, base maps as well as legends and scale of the map and implement the basic functions of a web app like zooming and panning. The three base layers: Open Street Map (OSM), Black and White OSM, and OpenTopoMap as alternative base maps have been configured. After configuring the main map layers and base layers, the shapefiles or vector layers prepared in the Mapfile are visualized as WMS layers as shown in Figure 8.

Figure 8 : Web GIS Application showing the Basic Features

Figure 9 : Highlight feature and Land properties

The most significant feature was to create a simulation, which is achieved by developing a dynamic layer. The main objective of the dynamic layer is to retrieve the information of land's area, floor space, living space in m² and potential residents of respective lands through a "Slider" feature, where the slider value determines the more potential percentage of the calculated attributes. Therefore, with every adjustment of the slider value, the value of floor space, living space and number of resident's updates. Three necessary calculations to simulate housing potential and demand were:

$$\textit{Floor Space (in m}^2\textit{)} = \textit{Total area of the respective lands} / \textit{Average of the GFZ of respective lands} \quad (3)$$

$$\textit{Living Space (in m}^2\textit{)} = \textit{Floor Space} - 20\% \quad (4)$$

$$\textit{Number of Residents} = \textit{Living Space} / 75\ \textit{m}^2 \quad (5)$$

Firstly, different views were created in the database to develop the dynamic layer. Based on the analytical requirements, the information automatically refreshes according to the slider value (user input) in a dynamic way. This has been developed using PHP in the leaflet framework. The dynamic layers are used to evaluate the simulated changes in floor area, residential floor area and the number of potential residents based on the specifications provided by the user, such as the percentage of owners willing to further develop their respective lands.

A HTML based dynamic chart has also been created for better visualization and interpretation of the calculated attributes. Thereafter this has been added as a hyperlink with PHP in leaflet. Apart from the dynamic features, few other interactive and user-friendly features have been added to make the application more user-friendly. Likewise, for accessing the layer by the user in a simple way, radio buttons and check box have been integrated in the application as shown in the following figures.

Figure 10 : Building Gaps where 50% of the Land Affected will be Further Developed

Figure 11 : Building Gaps where 100% of the Land Affected will be Further Developed

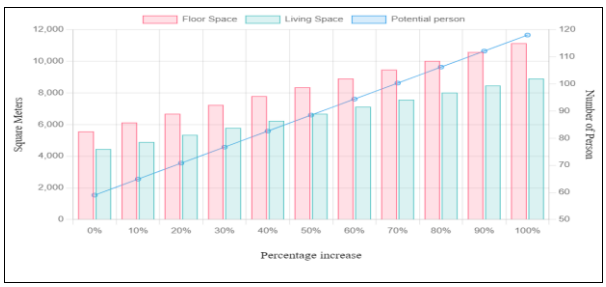

Figure 12 : Chart Showing the Potential of the Land in Terms of Floor Space (m²), Living Space (m²) and Number of Residents.

3. ANALYSIS RESULTS

3.1. Simulation of housing potential

The above described results show how the Web GIS application is structured, how the data are visualized, and which functionalities are implemented. The research objective of the whole study was firstly to identify and simulate housing potentials, secondly to simulate the housing potential according to realistic temporal availability and thirdly to check whether the predicted housing demand matches the simulated potential in the district of Eggingen. The simulation of the land development was carried out according to the given planning law and land use plan of the study area. Comparing all the existing types of potential housing areas together, the following results can be stated:

Potential Housing Areas	Attribute	Further Development (%)									
		0	10	20	30	40	50	60	70	80	90	100
Building Gaps	Floor Space	5570,00	6127,00	6684,00	7241,00	7798,00	8355,00	8912,00	9469,00	10026,00	10583,00	11140,00
	Living Space	4456,00	4901,60	5347,20	5792,80	6238,40	6684,00	7129,60	7575,20	8020,80	8466,40	8912,00
	No. of Residents	59,00	64,90	70,80	76,70	82,60	88,50	94,40	100,30	106,20	112,10	118,00
Building Application	Floor Space	1172,00	1289,20	1406,40	1523,60	1640,80	1758,00	1875,20	1992,40	2109,60	2226,80	2344,00
	Living Space	937,00	1030,70	1124,40	1218,10	1311,80	1405,50	1499,20	1592,90	1686,60	1780,30	1874,00
	No. of Residents	12,00	13,20	14,40	15,60	16,80	18,00	19,20	20,40	21,60	22,80	24,00
Underutilised Parcel	Floor Space	4981,00	5391,10	5881,20	6371,30	6861,40	7351,50	7841,6	8331,70	8821,80	9311,90	9802,00
	Living Space	3921,00	4313,10	4705,20	5097,30	5489,40	5881,50	6273,60	6665,70	7057,80	7449,90	7842,00
	No. of Residents	52,00	57,20	62,40	67,60	72,80	78,00	83,20	88,40	93,60	98,80	104,00
Outer Potential Area With Planning Right	Floor Space	17907,00	19697,70	21488,40	23279,10	25069,80	26860,50	28651,20	30441,90	32232,60	34023,30	35814,00
	Living Space	14326,00	15758,60	17191,20	18623,80	20056,40	21489,00	22921,60	24354,20	25786,80	27219,40	28652,00
	No. of Residents	191,00	210,10	229,20	248,30	267,40	286,50	305,60	324,70	343,80	362,90	382,00
Built-Up Areas	Floor Space	193697,00	213066,70	232436,40	251806,10	271175,80	290545,50	309915,2	329284,90	348654,60	368024,30	387394,00
	Living Space	154957,00	170452,70	185948,40	201444,10	216939,80	232435,50	247931,20	263426,90	278922,60	294418,30	309914,00
	No. of Residents	2066,00	2272,60	2479,20	2685,80	2892,40	3099,00	3305,60	3512,20	3718,80	3925,40	4132,00
Outer Potential Area With Land Use Plan	Floor Space	20093,00	22102,30	24111,60	26120,90	28130,20	30139,50	32148,80	34158,10	36167,40	38176,70	40186,00
	Living Space	16075,00	17682,50	19290,00	20897,50	22505,00	24112,50	25720,00	27327,50	28935,00	30542,50	32150,00
	No. of Residents	214,00	235,40	256,80	278,20	299,60	321,00	342,40	363,80	385,20	406,60	428,00

Figure 13 : Simulation of the different potential housing areas

Figure 14 depicts that the floor space is higher overall in the outer potential areas designated in the preparatory land use plan (outer potential area with land use plan) and consequently the living space and the potential number of residents are higher. This type of potential housing area belongs to the long term development, which means that development by the municipality can take up to a decade, but it has the highest potential for housing population. The type “outer potential area with planning right” represent an area, which is spatially defined by a binding land use plan and its specific requirements concerning type and degree of building use. It is the second highest in terms of floor area, living space and number of residents, which falls under the mid-term availability of development (waiting time for construction realization about five years). Gaps between buildings are the next to be used and can be developed immediately. Underutilized lands follow next, which can be developed by two to five years and the plots for which building applications have already been submitted to the building authority are the lowest in terms of these previously mentioned attributes. Therefore, it can be stated that the land in the outer area have the highest capacity to accommodate a high population.

Practice shows that 100% of the potential can only be realized to a limited extent from current planning, new construction activity in outer and inner areas, and development of building gaps. The reasons are ownership structures and planning lead times, resulting in restrictions or time delays.

3.2. Demographic forecast

After the calculated simulation, the analysis was compared with the population forecast of Eggingen, provided by the city of Ulm, department of city planning, environment and building law. The forecasting method used in the demographic prognosis is called ‘annual population forecast'. It is based on models that calculate the annual change of each age cohorts within a territorial unit. Starting from a population stock differentiated by 100 age groups and sex, the simulation models calculate the stock in the following year, considering the movement masses 'births', 'deaths per age cohort', 'in-migration and out-migration per age cohort'. This process is repeated for each projection year until 2040. The method calculates two scenarios and the mean average. (See Figure 14).

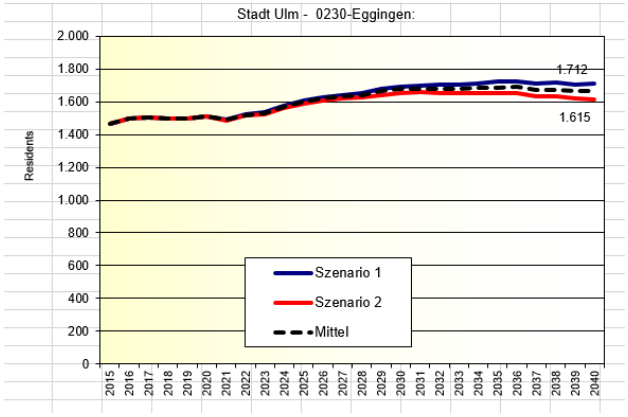

Figure 14 : Chart Showing the Prognosis Data (Municipality of Ulm)

3.3. Simulation results

Demographic projection data for the district shows that the total population in 2015 was 1.464, which is projected to increase to 1.712 in scenario 1 and 1.615 in scenario 2 until 2040. Considering the maximum possible increase in population (i.e., 1.712-1.464 = 248), scenario 1 was applied for further analysis. To meet the demand of the forecasted demographic data, combinations of different types of residential areas (see Figure 14) were considered in more detail (see Table. 2). Further combinations could be compiled individually depending on the readiness of a constructional realization.

Combination of potential housing areas	Availability of Parcel	Further Development %	No. of Potential Residents
Combination 1	Short Term (Building Gaps and Building Application)	100	142
	Mid Term (Underutilised Parcel)	100	104
Combination 2	Short Term (Building Gaps and Building Application)	40	98
	Mid term (Built-up Areas)	10	206
Combination 3	Short Term (Building Application)	60	19
	Mid Term (Outer Potential Area With Planning Right)	20	229
Combination 3	Mid Term (Outer Potential Area With Planning Right)	30	248
Combination 4	Long Term (Outer Potential Area With Land Use Plan)	20	256

Table 1 : Combination of potential residential areas to meet need of prognosis data

According to the simulated population and the review of the given population scenarios, it can be stated that the district of Eggingen has a much larger potential for housing development than it needs. However, the consequences of population developments are not yet foreseeable (e.g., further consequences of the Corona crisis, further allocations of asylum and refugee groups, spatial persistence of mobile population groups, etc.). The study shows that the small district of Eggingen could offer additional housing capacity if the population deviates from the projected figure if new developments lead to an increase in population.

4. CONCLUSION AND FUTURE STEPS

The implemented application provides decision-makers with a tool that helps them to meet the increasing demand for housing by showing the impact of planning changes or requirements within the given planning law. In addition, the distinction between short, medium and long term availability of building land supports decision-makers regarding the time horizon of development.

The city of Ulm with its associated districts is an emerging city with a growing population and is therefore particularly suitable as a pilot project for the simulation related to the new Building Land Mobilization Act. The research work helps the responsible municipalities to apply the new law in a targeted manner in order to better meet the growing housing demand, in which various socio-demographic scenarios can be played out and visualized. The analysis was compared with the demographic forecast data for the Eggingen district provided by the City of Ulm, Department of Urban Planning. In order to meet the requirements of the forecast data, various scenarios were analyzed.

Based on the housing simulations of different types of potential housing areas and the given population forecast the municipality of Eggingen holds a significantly higher housing potential than it needs under the assumed conditions. But the latest political developments show that there could well be a huge influx of people in the short term, which would lead to a much higher housing demand.
Due to time constraints and by the experiences of the development of the prototype the following topics are recommended for future work.

- The virtual 3D city model can be integrated in the existing application showing the land use and the topography of the surrounding of Eggingen district.
- The 3D data of buildings would allow a better representation of the structure and the simulation of building additions and extensions could be shown more realistic.
- Based on 3D city model simulations could be carried out on different levels, e.g., of single buildings, city quarters, entire cities and regions.
- Other editable functions such as user editing, map layout printing, measurement functions etc. can be added for enhance the user experience.

In summary, the Web GIS Application supports urban planners and decision makers of the municipalities in developing their residential areas to meet the increasing demand for housing.

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