The vertical morphology of informal areas. A case study in Kabul city

MOHAMMAD SHAHID KOBAKIWAL

Faculty of Geo-information Science and Earth Observation, ITC, University of Twente, Enschede, The Netherlands, August 2021

Specialization: Urban planning and Management

SUPERVISORS:
dr. M. Kuffer (Monika)
dr. M.N. Koeva (Mila)

Thesis Assessment board:
Chair: Prof.dr. K. Pfeffer
External examineer: Dr. Maik Netzband

.

DISCLAIMER

ABSTRACT

Mapping the informal settlements based on Earth observation satellite data has progressed significantly. However, only the two-dimensional representation of the informal settlements is provided by current approaches. As a result, a complete characterization is limited in urban morphology, which can only be obtained through a thorough examination of the vertical settlement extent. Therefore, this study is aimed to identify the types and patterns of vertical morphologies of informal settlements and develop a 3D model of these morphologies for planning decision making using earth observation techniques in Kabul. To synergize various types of data planning and to develop the 3D model, the geographical information system was applied (GIS). A set of urban morphology maps, land surface maps, and building height maps were merged to create Local Climate Zones (LCZs) maps by following the standardized procedure proposed by the LCZ framework to identifying types and patterns of vertical morphologies. Next, the physical difference and locational factor analysis were conducted for identified vertical morphologies. The 3D model is developed at a block level to analyze the vertical morphology types, patterns, and distribution. The 3D model was processed in GIS extension, ArcGIS Pro. The building footprints are manually digitalized using UAV images with 10 cm resolution, and building height information is accessed from UN-Habitat field survey data (MIS data). The procedure ended with a 3D model that shows the types and patterns of identified vertical morphologies. This study used an integrative GIS-based method to analyze various types of planning data for analyzing the vertical urban morphology of informal settlements in Kabul, which is also applicable to other cities with an extensive range of planning information.

ACKNOWLEDGEMENTS

I would like to express my greatest gratitude to my supervisors Dr. Monika Kuffer and Dr. Mila Koeva. Thank you very much for your patience and guidance, and for giving me the opportunity to conduct this research with you. Your passion inspired me much and helped me to think critically while remaining optimistic. This had great honor for having your supervision.

I want to thank the Kabul Municipality and my colleagues for supporting me and providing me the needed data. More importantly the doing my field work in that unpleasant and challenging condition of the country.

There are my special thanks to my dearest friends here in Netherlands and Afghanistan for their continuous support and encouragement. I would like to thank the Dutch government for providing me the opportunity to study and learn from their experiences and knowledge.

Table of Contents

List of Figures

1 . Introduction – Research Problem

1.1 Background

Urban areas in the world are undergoing dramatic shifts in their urban scale and morphology. In 2015, about 54% of the world's population lived in cities, and by 2050 around 70% of the world's population is predicted to live in urban areas (United Nations, 2019). As people pursue an urban lifestyle with a commensurate quality of facilities, infrastructure, amenities, and living standards, the population growth and economic, social, and cultural activities are becoming highly concentrated in cities (Jones, 2017). This transition and continuing development of the urbanization process brings several planning challenges regarding sufficient and equal delivery of social services, housing and property, jobs, safety, education, and natural environmental protection (United Nations, 2017). To face these challenges, the United Nations stresses the importance of 'sustainable urban development' in the Sustainable Development Goals (SDGs) (Jones, 2017). Multiple environmental and development goals need to be realized to achieve SDGs 11 in cities. Thus, achieving sustainable development and urbanization requires developing social, environmental, economic, and city resources, which are also called their dimensions, where these dimensions are strongly intertwined (Jones, 2017).

One of the most significant impacts and consequences of urbanization, specifically in developing nations, is the proliferation and growth of informal settlements. Informal settlements and slums are commonly considered to be synonymous, but with particular emphasis on the formal status of the land, buildings, and services (Indicator, 2018). The continuing expansions of informal settlements added to the complexity of urbanization (Minnery et al., 2013). According to the UN-Habitat, those who live in such housing and settlements face a higher degree of spatial, economic, and social deprivation than other parts of the urban population (Jones, 2017). In the face of policies and strategies of sustainable urbanization in most global south countries, the governmental approaches failed to address informal settlements due to a lack of technical and financial capacity to develop and implement plans and policies (Minnery et al., 2013). As a result, informal settlements remain the twentieth century's greatest persistent sustainable urbanization challenge (Jones, 2017).

Informal settlements provide shelter for millions of poor urban residents in developing countries who cannot access adequate shelters through formal means. Over half of the urban population of developing countries and about 863 million people worldwide live in informal settlements (United Nations, 2017). Such residents are by nature vulnerable to various hazards and vulnerabilities due to highly dense population and absence of stable employment, a safe and sustainable living environment, lack of land tenure, and access to essential facilities such as drinking water, health care, and sanitation (Niva, Taka, & Varis, 2019). Besides, these settlements have to deal with precarious housing conditions, which also include: located in hazardous areas, overpopulation, and unsafe building structures (Sminkey & LeDoux, 2016). Despite the formality and precision of the above terms in national and global reports, such typologies of settlements tend to refer to illegal and often under-standard housing enclaves that occur in highly dense, diverse forms, shapes, and patterns in cities and towns (Jones, 2017).

When it comes to the forms of the informal settlements in terms of their physical and morphological characteristics, the dynamics and growth of informal settlements in these terms are not only happened in the horizontal dimension but also there are changes in the vertical dimension (Kamalipour, 2020). Many studies on informal settlements are concerned with the dynamics of informal settlements' physical, socioeconomic, and political processes. Most studies on physical dynamics focus on the horizontal dimension. However, the informal settlements show different urban characteristics because they are at various stages of development, and each settlement began its urbanization process at different periods (Taubenböck, Kraff, & Wurm, 2018). Despite this, little is known about informal settlement's vertical growth and morphologies (Amirebrahimi et al., 2016). Commonly, the vertical expansion of informal settlements happened gradually (Fekade, 2014). There are two development processes of vertical informal settlements, incremental and formal. In the gradual process, low-income inhabitants start by building a modest single room and a sanitary facility, gradually adding living space through a series of modifications to reach a two or more-story house eventually. In the formal process, development is accomplished first by the formalization of lands (through upgrading or other planning schemes), mostly as a single land plot (not an area), and then the landowner himself or with the assistance of land developers and real estate entrepreneurs, who construct residences ranging from three to six stories, which has become a typical trend in the vertical growth of informal settlements (Fekade, 2014).

In recent years, for detecting physical and morphological characteristics of vertical urban informal, many techniques have relied on digital elevation data generated from very high-resolution aerial and satellite images and ranging (LiDAR) (Xu et al., 2019). Shahzad & Zhu (2015) suggested the SAR tomography method that recreates the position and height of structures with very high spatial precision. However, because of the extensive data stacks requirements, this approach has only been used in research on a city or regional scale in the global south.

For reliable detection and delineation of the vertical informality in dense and homogenous areas, automatic and manual methodologies can be used, for which high-resolution EO data is required. In many urban cities, informal settlements' data (horizontal and vertical dynamics) are rarely available (Taubenböck et al., 2018). For this reason, this study focuses on analyzing the pattern of vertical informality and their morphological types based on EO and referenced data.

1.2 Research Problem

The studies and practices of urban planning always have focused on the qualitative and quantitative analysis of the horizontal condition of informal settlements and their impacts on socioeconomic conditions over the last five decades (Taubenböck et al., 2018). There is no systematic research regarding approaches to studying urban informality's vertical dynamics (Jaitman, 2013). In the upcoming years, various studies need to underscore the need to obtain a more significant amount of knowledge on these settlements (Taubenböck et al., 2018). The dynamics and presence of vertical growth of informal settlements are relatively extensive, and academics describe the reasons for the dynamics and existence of vertical informality in developing nations as a rise in population densities in informal or slum regions, a shortage of land, and changes in socioeconomic conditions (Debnath et al., 2019).

Today, in most developing cities, it is challenging to access non-built (green) land and central locations. Hence, the only possible way to access land and economic networks are that informality is to grow in vertical dimension in these cities (Ribeiro, Jarzabek-Rychard, Cintra, & Maas, 2019). Another issue that causes the growth of a vertical form of informality is the failure in planning and implementation processes of governments in developing country cities, such as the vertical growth of informal settlements in Mumbai, India (Sminkey & LeDoux, 2016). Many social housing schemes were implemented in the city with low quality and living standards; later on, the buildings were transformed into vertical slums (Taubenböck et al., 2018).

Most planning interventions in informal settlements currently claim to 'integrate' those areas and their residents into the formal city. During the integration process, the definition of the vertical dimension of informal settlements and their impacts has been commonly ignored by decision- and policy-makers (Jaitman, 2013). Consequently, a spatial qualitative and quantitative description of vertical informality is lacking, where it also creates challenges for practitioners when designing and implementing policies. For these reasons, it is essential to have a better grasp of the vertical form of informal settlements and to question the current planning practices in this field to inform future decisions and policymaking (Debnath et al., 2019).

On the other hand, studies that address informal urban growth differ considerably across the globe (Taubenböck et al., 2018). Kabul is one of the cities where informal growth is significant and has received considerably less attention, in particular, horizontal and vertical dimensions. The lack of studies and accurate and up-to-date data sources of vertical informality failed the Kabul authorities in integrating informal settlements, which brought many other social and economic challenges in Kabul city (Kabul Municipality, 2015). These issues raised the interest of Kabul authorities to understand the dynamics of vertical informality in details and cost-effective manner and help the authorities in better assessment and implementation of plans and policies in the future (Amiri & Lukumwena, 2018).

Scholars typically mention many reasons for lacking comprehensive datasets, such as the scale at which a case is globally or locally presented, ignorance of the other aspects of the problem, planning and policy processes, and cost (Shahzad & Zhu, 2015). EO provides autonomous, area-based, and up-to-date data suitable for physically analyzing informal settlements and spatial patterns. In recent years, EO techniques have evolved to the degree that they can make a substantial contribution to mapping, characterizing, measuring, and thereby describing the structure, morphology, and environments of urban areas (Jones, 2017). Datasets generated by these EO methods have been employed in various applications, by which they commonly reflect only in two-dimension (2D). To phrase it another way, any extensive and successful assessments of the informal settlements in terms of volume or floor space and urban morphology must necessarily include the vertical dimension (Dovey et al., 2020). In this regard, detailed studies on the three-dimensional (3D) of urban structures of informal settlements at the city level are required, relying on different EO techniques.

Besides, the knowledge of 3D data modeling with EO techniques can be carried on to cities with specific spatial and demographic settings (Taubenböck et al., 2018). It can also be anticipated that the 3D data modeling of vertical morphologies would have several other applications to boost our capacity to consider urban development dynamics and their impacts on socioeconomic conditions (Debnath et al., 2019). The integration of 3D modeling in different fields turned the attention of many researchers such as Li, Koks, & van Vliet (2020) and Taubenböck & Kraff (2014) to apply 3D modeling with the help of EO techniques to analyze the 3D building structures of informal settlements. Since the economic, social, and spatial integration of vertical informality with their urban context increased complexity in their dynamics. In this regard, few studies have been done to systematically integrate 3D and EO data to analyze the vertical dynamics of informal settlements. Therefore, this research will analyze vertical morphologies and dynamics of vertical informality in Kabul city.

1.3 Research Objectives:

General Objectives:

To develop an integrative 3D data method based on EO techniques for analyzing the types and patterns of vertical informality in Kabul.

Sub-objectives:

1. To identify the vertical morphology of informal settlements in Kabul.
2. To investigate 3D data methods for creating a 3D model to analyze the vertical patterns of informal settlement by literature review.
3. To assess the future practical application of the model by interviewing urban planning experts and practitioners.

1.4 Research Questions:

The research question for sub-objective 1. To identify the vertical morphology of informal settlements in Kabul.

- What are the major types of vertical morphologies in Kabul?
- Do these types of vertical morphologies have definite physical differences compared to one another?
- What are the locational characteristics of these vertical morphologies?

The research question for sub-objective 2. To investigate 3D data methods and creating a 3D model to analyze the vertical patterns of informal settlement.

- What characteristics of vertical informality can be measured by building a 3D model?
- Is the vertical informality of Kabul city in its physical terms are homogeneous or heterogeneous?

The research question for sub-objective 3. The assessment of the future practical application of the model by interviewing urban planning experts and practitioners.

- What role the 3D data modeling can play in urban planning on informality?

1.5 Conceptual Framework

The overall framework for 3D data modeling analysis of vertical informality is based on EO principles with an urban morphology viewpoint. The vertical dimensions of formal and informal settlements are packed with the study of EO and urban morphology that can support a comprehensive determination of 3D modeling multifunctionality. The framework shows the interrelationship among the concept of vertical informality, EO techniques, and 3D data modeling towards the analysis of vertical patterns. The framework shows that the information on one component is merged with the information of another. Figure 1 illustrates the research framework to achieve the objective: analysis of vertical patterns of informal settlements.

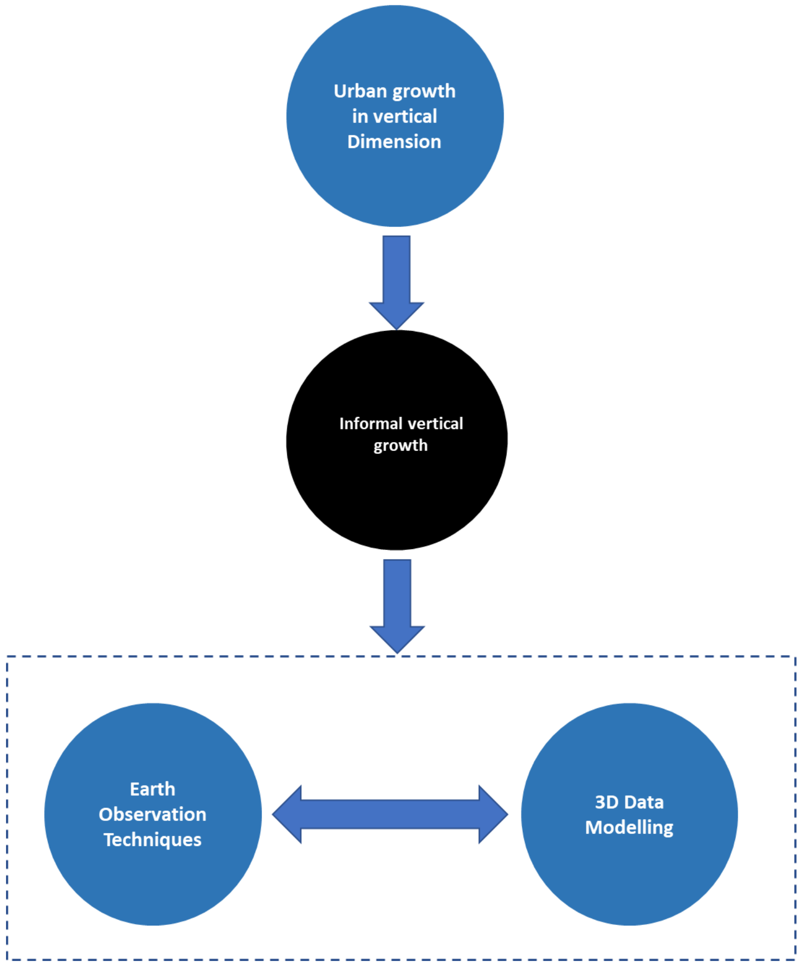


Figure 1: Conceptual framework towards vertical patterns of informal settlements.

2. Literature Review

2.1. Introduction

The morphology of informal settlements has received little attention in the literature. A few studies have focused on analyzing morphologies of informal settlements in a global setting based on specific geographical parameters (Taubenböck et al., 2018). As it is sometimes hard to offer an exact definition of morphologies of urban informality, the term has been used in a variety of ways throughout the last few decades. The term applies to certain urban architectural principles, distinguishable sociological units, and the spatial arrangement of urban structures (Dovey, van Oostrum, Chatterjee, & Shafique, 2020). Planners attempt to differentiate between land use and urban structure. Urban structure, a more general term, is defined as the arrangement of actual and future land use in urban areas (Taubenböck, Kraff, & Wurm, 2018). When seen in this light, the structure can be associated with the spatial structure of the urban area, which is concerned with the configuration of public and private spaces in cities and the rate of density and connectivity of the functional elements. Batty et al. (2008) introduces and explains models that represent urban dynamics in the sense of the theory of complexity in terms of the roles of space and the city as an area of interactions. These models connect various scales of urban structure and develop complexity concepts to connect urban structural dynamics with local or regional interplays (Batty et al., 2008).

The term urban morphology is often used interchangeably with urban structure. Urban morphology itself is defined as a study of the human habitat in the cities, which suggests that urban morphologists are interested in the observable outcomes of social and economic factors (Moudon, 1997). Given the fact that the other writers reference various lines of thought concerning urban morphology. As Gauthier & Gilliland et al. (2006) defines the urban morphology as a form of the city, and according to Batty et al. (2008), urban morphology is the process of city transitions, the functions of space, and the relationship to specific socioeconomic dimensions, which are all intrinsic components of this area of study.

Urban morphology is related to the studies of the formation of human habitation and the mechanisms that shape and transform them (Moudon, 1997). The origins can be found in geography and urban sociology, where researchers attempt to explain the geographical nature and character of an urban environment by studying the patterns of its constituent components, as well as the ownership and use of dwellings (Golding, Ashton, Marsh, & Thompson, 1986). Nonetheless, urban studies were based on various schools of thought, each with its own set of goals and social hypotheses. Only recent research on urban structure objectification has attempted to establish neutral, strictly descriptive views of cities (Hecht, Herold, Meinel, & Buchroithner, 2013). When we consider the urban morphology in studying a metropolitan area, the structure term becomes the central concept (Batty et al., 2008). Since in the context of Urban physical structure, and especially in light of the growing concerns for the development of informal areas, the urban structure types concept introduced by the remote sensing community will help us understand the spatial and physical dynamics of an urban fabric.

Understanding the dynamics and content of the urban structures has therefore become an essential component of political frameworks. In this case, up-to-date and internationally consistent data on the state and features of the urban structures are at the heart of national and local programs to achieve sustainable development (Jones, 2017). However, considering the rapid global urbanization's dynamic, such data are still a scarce resource. In recent years, the EO has been used in identifying the typologies and elements of urban structure types globally indifferent horizontal extents (Ribeiro, Jarzabek-Rychard, Cintra, & Maas, 2019). Whereas data derived from EO has various applications, there are still limitations in using the data (Shahzad & Zhu, 2015). In this regard, detailed use of three-dimensional)3D) studies of urban structure types and their elements are widely published by many scholars (Dovey, van Oostrum, Chatterjee, & Shafique, 2020). The urban structures are defined by the spatial features, such as the morphology and types, and spatial associations between urban elements such as buildings, road networks, trees, and lawns (Hecht et al., 2013).

2.2. Urban Structure Elements and 3D Modeling

The urban structure has been defined at the city level as the spatial configuration of fixed elements. However, the physical characteristics of the urban structure are strongly connected to scale, and it has been defined as the morphological characteristics of an urban region (Dovey, van Oostrum, Chatterjee, & Shafique, 2020). Therefore, these characteristics can range from a very local scale such as building materials, façades, and fenestration to a broader scale such as building types, street patterns, and spatial configuration (Heiden et al., 2012). According to Fullilove (2018), the urban structure comprises three elements: Space, movement, and building. Space refers to an area's underlying topography, natural characteristics, and environment. The movement refers to the road networks, walkways, bike lanes, paths, and transportation infrastructure and services that it supports. The buildings in contexts of the urban structure are defined by their physical characteristics, scale, and height (Fullilove, 2018).

By many planners and practitioners, urban structure is considered as a principle for detailed planning and design of each element, and these elements provide a framework of guidance and influence on the current and future interaction and dynamics of individual buildings, infrastructure, and spaces (Dovey et al., 2020). These planning and design include measures to guarantee that the urban structure is well-planned and capable of supporting a sustainable urban community. In many countries, specifically in developing countries, urban planning practitioners (municipal and national level) have found it challenging to implement these planning and design scenarios and to control urban developments. Furthermore, statutory planners devote a significant amount of time to decide whether development plans in diverse metropolitan regions satisfy the basic standards set out in planning regulations. As a result, it is critical for the planners to have the correct toolset to prepare for future developments and evaluate current dynamics (Kyttä et al., 2013).

In many of the world's cities, urban planners use two-dimensional (2D) information of these elements to control and evaluate the impacts of the current and plan the future development of the cities. There have been many advancements in EO technology in the context of 2D models to represent this information. Still, there are many limitations in using primary data and modeling methods for assessing the impacts, design, and decision-making at municipal, national and global levels (Sabri et al., 2016). In addition to their specific uses, these models and data have the potential to have considerable significance in the interpretation of urban structures, as well as the mechanisms of urban development, spatial planning, and planning in a broader context (Hecht, Herold, Meinel, & Buchroithner, 2013).

The recent developments in 3D and EO technologies aim to enhance decision-making processes by assessing the possible effects of development plans, visualizing urban planning and design effects, and enabling users to experience them from different perspectives (Kyttä et al., 2013). The use of 3D models with the help of EO technologies is especially effective in visualizing urban structures elements and built environments, allowing the relevant details to be delivered in an intuitive way (Hecht et al., 2013). The 3D visual representation is also a beneficial tool for the mental image of the planners and stockholders. For example, at the object level, the 3D visual models allow people to measure the impact of buildings on their surroundings and provide a framework for evaluating the potentials of the 3D projects. Furthermore, the multi-dimensional GIS visualizations can have predictive elements, allowing planners, specifically at the municipal level, to hold effective discussions about future developments of the cities (Yin, 2017).

Scholars investigated 3D analytics and simulation of urban structure elements in various spatial planning and urban architecture studies, such as detection of building shadow and its impacts (Alam, Coors, & Zlatanova, 2013), analysis of walkability (Yin, 2017), and planning for the flood-prone areas (Amirebrahimi et al., 2016). The scholar Kyttä et al. (2013) studied the role of 3D modeling in the public consultation for a critical inner-city's urban development process. Glass et al. (2006) studied the duplication of urban form and road patterns of informal settlements in three-dimension (3D). In these studies, the applications of 3D data methods differ from one another. Still, they all have two things in common: EO and GIS technology play a critical role throughout the modeling process, from data capture to automatic extrusion to product utilization and management.

The development of 3D urban models depends on two factors: a spatial information database and EO data technologies. Scholars, these two factors will play a vital role in integrating the 3D urban models (Yin, 2017). However, the ability of software package to produce fine, regular models is essential. Examples are desktop GIS versions like ArcView, ArcGIS Pro, and the Evans and Sutherland quick 3D modeling software packages. More advanced software packages such as Multigene Paradigm, blender, and City Engine incorporates EO data in producing detailed 3D urban models (Lehner & Blaschke, 2019). Furthermore, the use of these 3D modeling approaches has two opposing trends. They are likely more product and demand base from one side, customized to meet specific demands for each use, resulting in many more variations; In contrast, the needs for data and model consistency necessitate adopting a standard protocol and metadata by 3D models (Yin, 2017).

2.3. 3D Modelling of Informal Settlements

It is difficult to define general mapping rules for informal settlements due to the high density and physical growth of informal settlements in specific locations. Furthermore, informal settlements are barely distinguishable from formal settlements based solely on their physiognomy (Barros, 2009). Mapping informal settlements is a challenging task because it necessitates the incorporation of local knowledge and the adaptation of specific characteristics; according to Duque et al. (2017), there are three spatial levels of mapping the informal settlements: the environment level, settlement level, and object-level (Duque et al. 2017; Kholi et al. 2012).

An expert group meeting was held in 2008 (Sliuzas, Mboup, & de Sherbinin, 2008), which resulted in the initial concept of qualitative and quantitative metrics for slum detection at settlement level from VHR remote sensing results. Since then, numerous EO studies have aimed to expand spatial awareness of informal settlements. Kohli et al. (2012) created a generic ontology of slums for image-based classification. In either case, optical data from VHR have been commonly used to detect and assess slums. Few other studies used radar data to detect informal settlements (Stasolla & Gamba, 2008). Many experiments, conceptually, focus on the block stage, attempting to delineate illegal settlements within the built environment. Taubenbock and Kraff (2014) demonstrated in this sense that the morphological and structural features of informal settlements could vary significantly from those of neighboring formal urban areas. Object-based algorithms (Peter, Friso, Sisi, & Elfriede, 2008), snakes (Rüther, Martine, & Mtalo, 2002), radial casting algorithms (Kyttä, Broberg, Tzoulas, & Snabb, 2013), and visual classifications (Joshi, Sen, & Hobson, 2002), have all been used to exploit morphological differences in informal settlements appearance in remote sensing images.

Duque et al. (2017) describe the primary components of the mapping of informal settlements at the object level: building and road features. Many studies used a manual derivation of spatial characteristics of single buildings such as building size, shape, height, and density and distribution (Hofmann, 2014; Kemper & Pesaresi, 2019). At the level of individual buildings, techniques are often limited to visual representations due to the high density of buildings, geographic overlapping of roofs, and heterogeneous configuration, which do not yet allow for accurate automated spatial differentiation of individual structures. However, research on structural analysis at the individual building level is still uncommon (Ranguelova et al., 2019). Pan et al. (2020) suggest that a high accuracy detection of morphological and physical aspects of the informal settlement requires the availability of high-resolution EO data. Informal settlements are dynamic, and their existence is complex by default; only approaches that allow for in-situ, and in some cases, in-vivo (e.g., volunteered mapping) information retrieval is sufficient, including the geo-information (Joshi et al., 2002). Creating realistic scenarios of informal settlement growth, on the other hand, is only possible if the models are fed with extensive knowledge of the genesis steering mechanisms (Dovey et al., 2020). As a result, the better the knowledge gathered, the better the models can be tested and calibrated, which increases our insight into the mechanisms (Batty, Axhausen, & Fosca, 2008). In this case, the 3D operation can identify and model, and expand details and expertise on various aspects such as their location and development in the broader urban context (Li, Koks, Taubenböck, & van Vliet, 2020).

In the application of urban planning and design, Three-dimensional (3D) models are becoming more common. The information that a 3D model can present cannot be visualized in 2D (Wergles & Muhar, 2009). By understanding the advantages of 3D visualizations, many German municipalities provided 3D models with a level of details (LOD)2 for their municipal areas and LOD3 for their city centers. Other European cities, such as Rotterdam, Monaco, Geneva, Zurich, and Leeuwarden, also use 3D city models to reflect and exchange data, as do Asian cities (Li et al., 2020). Many other studies reflected on different aspects of 3D modeling, but these studies are limited to the formal urban environment (Yin, 2017). The use of 3D modeling for informal settlements can also be part of 3D applications. However, the research on 3D modeling for informal settlements is limited to exploratory studies in a few countries (Li et al., 2020).

2.4. 3D Data Framework

Planning and implementing projects related to the informal settlements to improve the living condition necessitates the use of up-to-date base maps that adequately depict the local on-ground reality. For instance, identifying buildings' physical characteristics while categorizing topography identifies roads for accessibility and utility design or open space for infrastructure placement (United Nations, 2017). Satellite photography is considered a significant source for creating base maps of the physical characteristics of informal settlements. However, informal settlements are generally defined by high densities of buildings, irregularity of buildings, and narrow streets; require high-resolution images (e.g. drone images), as VHR images failed to extract needed information (Gevaert, Persello, Sliuzas, & Vosselman, 2017). From overlapping aerial images, 3D point clouds, photogrammetric processes may generate 2D orthomosaics, 2.5D Digital Surface Models (DSMs), and 3D point clouds. However, aerial and UAV images UAVs enable more flexible and rapid data gathering (Kemper & Pesaresi, 2019).

According to Taubenböck & Kraff (2014), there is no specific framework to develop a 3D model of informal settlements. However, in a general context, the 3D data method should consider and demonstrate these three critical factors in constructing the model (Kemper & Pesaresi, 2019): the degree of reality, types of data input, and the degree of functionality. The extent of variation displayed within each element demonstrates the modeling diversity (Gevaert et al., 2017). Leavitt and Neal (1999) describe that the amount of information captured and replicated within the model determines the degree of reality. This explains that the more details needed to be added, the more data and resources are required. How these data and resources are collected affects the model's final output. They also added that functionality is probably the most critical aspect in terms of the model's demand and application. Photorealistic CAD-type models and CG parses are frequently less robust, whereas GIS-based models are usually accompanied by significant attribute data and are integral to specific analyses. Although the number of analytical features does not always define a model's utility in its proprietary sense, the scope for comprehensive and alternative applications will be specifically expressed where GIS will prove to be an efficient tool in this regard (Holtier, Steadman, & Smith, 2000). The implementations of the 3D model in an urban arena differ from one another. Still, they all have one thing in common: GIS technology plays a critical role throughout the modeling process, from data capture to automatic extrusion to product utilization and maintenance (Yin, 2017).

Kyttä et al. (2013) stressed that the 3D modeling scenes benefit from GIS's extensive capabilities and computational capabilities and its database structure's multiple queries feature. Additionally, the spatial information and EO techniques database are two main factors that the 3D modeling depends on. Due to the rapid adaptation of information technologies, these two factors have become standard features of 3D models. The emergence and development of GIS plugins and extensions in the generation of standard 3D models, and their applicability with other 3D modeling software packages such as blender, CityGML, and BIM, is another reason for the better application of 3D modeling in the urban arena.

The urban studies that used GIS-based 3D data model frameworks (Figure 2) such as Yin (2017), walkability quality in street-level by 3D GIS measure, Taubenböck & Kraff (2014), the physical face of informal settlements and slums, and Holtier et al. (2000), 3D analysis of urban forms, authors used general GIS-based 3D data method. Figure 2 summarizes the above studies, showing a GIS-based 3D data method to analyze the vertical patterns of informal settlements.

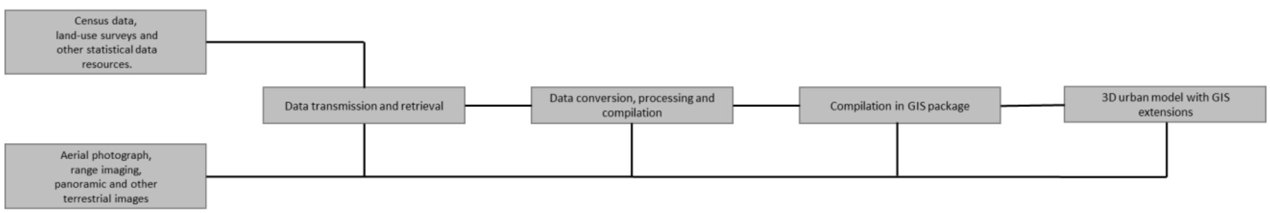


Figure 2: A Method for 3D data modeling in a GIS environment.

For an adaptation of a GIS-based 3D data method, a procedural modeling approach is commonly used. The procedural modeling approach applies rules to a 2D shape, which is then replaced by a 3D object (Koenig & Bauriedel, 2009). Natural real-world structures can be realistically simulated using procedural modeling because it employs parameterization, which allows for unlimited variety in the created model. On the other hand, identifying the suitable parameters and values to create a photo-realistic model is impossible (Omar, El-Messeidy, & Youssef, 2016). Procedural modeling effectively creates models of urban landscapes, road networks, utilities, vegetation, and terrains. Since cities are large and highly complex, urban modeling is a major reason for procedural modeling's popularity (Smelik, Tutenel, Bidarra, & Benes, 2014). Developing a 3D model with such complexity with manual modeling is very time-consuming and tedious.

The procedural modeling process for developing of 3D model is done in two steps. Step one, includes 2D GIS data preparation. for example, the extraction of building footprints, trees, and road networks. The second step includes the building of a 3D model, which is implemented in ArcGIS Pro. Due to the high density and complexity of informal settlements of the study area, creating a geometrically accurate extraction of building footprints is a challenging task. With the automatic approaches for the detection of footprints of high-dens and complex informal settlements, large computational resources are required for image processing, which is time-consuming (Xu et al., 2019).

For better representation of the output of the 3D model in a realistic manner, there are different classes of the level of details (LoD). The LoD largely determines the applicability of the model (Morton, Horne, Dalton, & Thompson, 2012). Biljecki et al. (2013) proposed additional benefits

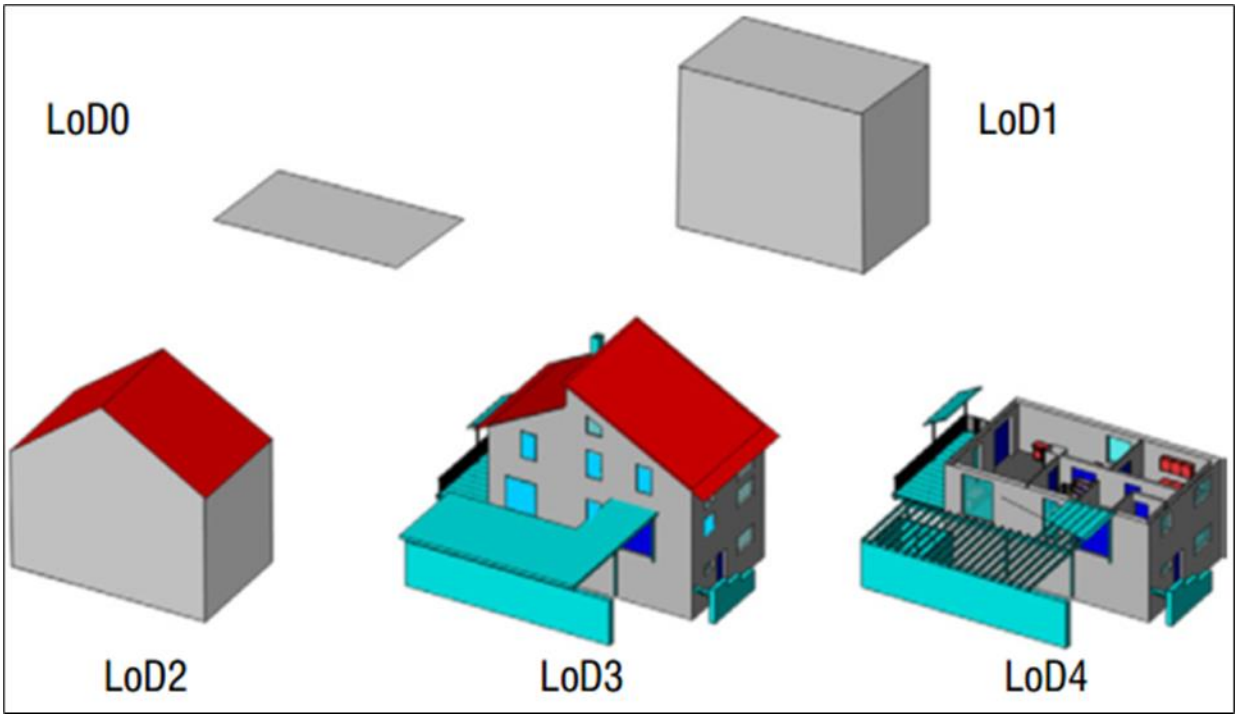


Figure 3: CityGML specifications of LoD (Source: Biljecki et al., (2013)).

for using LoD, such as specifying the stage at which 3D data is collected and generalization during rendering. Additionally, there are many ways to define LoD for urban models. None of the methods, however, are without critique. Some LoDs, for example, are deemed too coarse, preventing a seamless transition between layers (Biljecki, Zhao, Stoter, & Ledoux, 2013). The LoD CityGML specification from the Open Geospatial Consortium (OGC) will be used (Figure 3) (Biljecki et al. 2013).

The CityGML defines each specification as follows: LoD0 is the 2.5D representation of an object's simple outline, usually a flat polygon. The LoD1 is obtained by modeling the volume of structures in a generalized manner, including vertical walls and flat roofs. The LoD2 expands on LoD1 by including roofs and also texture on structures and terrain. The LoD3 is an expansion of LoD2 that includes openings such as windows and doors and more complex roof systems, and the LoD 4 adds more interior details of buildings.

3. Methodology

This is an analytical-oriented study on 3D modeling approaches to the vertical form of informal urban settlements. It employs a case study design since it is commonly accepted that the findings obtained from these are more rigorous. However, due to time and data constraints, this work is limited to just one case. For this analysis, both quantitative and qualitative approaches were selected because they are especially well suited for analyzing processes, behavior, and needs, which is critical when conducting analytical-oriented research. Furthermore, since the existence of the research questions necessitate the compilation of significant volumes of textual and numerical evidence, quantitative and qualitative approaches are particularly suitable for this analysis.

3.1. Study Area

3.1.1. Background

Afghanistan is a country located in the heart of Asia, with about 39 million population Worldometer 2020), suffering from conflicts for decades (Turkstra, 2010). Due to the high rate of urban migration from conflict areas, the urban areas in Afghanistan are proliferating, and currently, about 70% of the metropolitan regions are developed informally (Amiri & Lukumwena, 2018). The residence of informal areas includes migrants from rural and urban areas, returnees, internally displaced persons (IDPs), and the low-income population who need shelters to live (Sasaki, 2020). Unplanned development in the cities of Afghanistan is widespread and significant parts of the cities are developed informally (Nazire, Kita, Okyere, & Matsubara, 2016).

Afghanistan has traditionally considered a rural society as 75% of the population lives in the rural region, but it is predicted to decrease by 50% in 2060 (Kabul Municipality, 2015). Currently, Kabul city is the country's capital and a prime city with 22 municipal districts (figure 4). It has accommodated about 41% of the country's urban population, where 70 % of its urban areas are developed informally (Amiri & Lukumwena, 2018). In the last decades, Kabul has emerged as a commercial hub, but land use and development regulations act as barriers to investment in the city.

In the meantime, natural resources, such as farmlands in Kabul, faced infringement of informal settlements, and these settlements have become an inevitable manifestation in Kabul (Sasaki, 2020). Due to the expansion and development of the informal settlement, the key development components, such as infrastructure, environmental assets, employment, food systems, and tourism, are not addressed, fragmented, and neglected in Kabul city (Amiri & Lukumwena, 2018).

In Kabul, these dynamics are at play. As a capital city and the biggest metropolitan agglomeration in the country, Significant waves of migration and massive unplanned growth have resulted in the city becoming the region's most informally developed city. As once the city had the image, reputation, and as was known as "city of gardens." However, the new Kabul master plan named "Kabul Urban Design Framework" is planned to accommodate up to 8 million inhabitants by 2060. unfortunately, the authorities have been able to implement only 30% of the plan in Kabul; in the end, 70% of Kabul city has been developed informally (Collier et al., 2019).

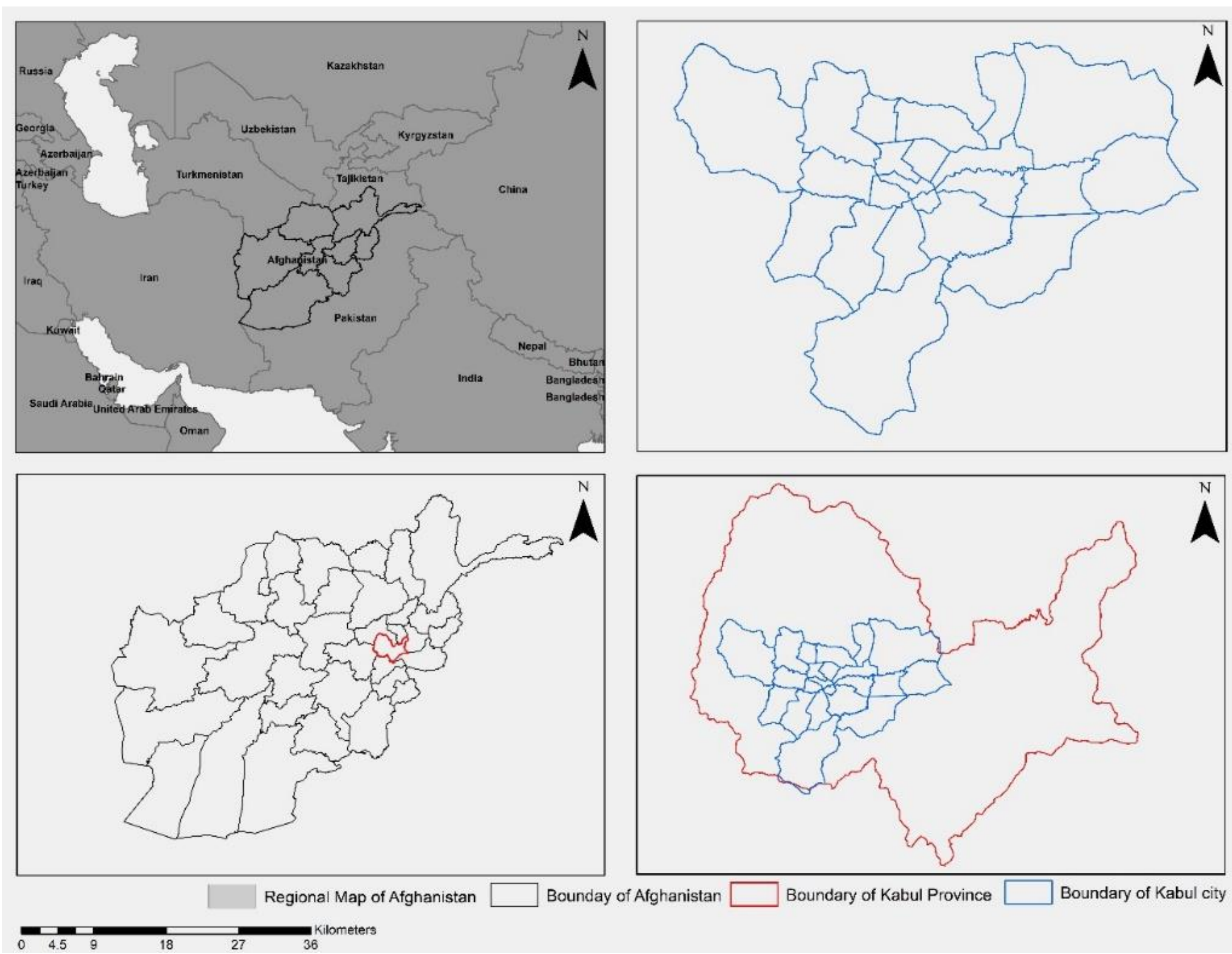


Figure 4: Afghanistan's regional and provincial boundary map, and boundary maps of Kabul province and district map of Kabul city. (Data source: ArcGIS Hub)

3.1.2. Current Planning Efforts in Kabul

The new era of urban development in Kabul started in 2001. In this year, it was estimated that Kabul had had approximately 1 million population. The subsequent urbanization in Kabul was caused by the continuous inflow of returnees, internally displaced people, and economic migrants from rural areas (APPRO, 2012). The two major government bodies are in charge, the Kabul Municipality and the Ministry of Urban Development and Housing (MoUD). Which have been under-resourced, poorly trained, and unable to establish appropriate policy responses and other modes of action to address the many needs of the large population of Kabul, which causes the spread of informal settlements in and around the Kabul city expensively.

Both service sectors were mainly using the master plan of 1978, where the population of Kabul city was around 1 million. That master plan was the plan to cater services for 2 million people, where the people of Kabul city were much larger than that (APPRO, 2012). The institutionalization of urban management encouraged the new government to develop a new master plan to respond to Kabul's growth. In 2011, a new master plan was created by JICA (known as the JICA Plan) (Figure 5a), which formed the first structure for city development. This plan introduced a range of core ideas, including a ring road, a retained agricultural belt, and a policy for development to align water resources with growth. Much has occurred in Kabul in the years after the announcement of the JICA plan. Most of the current developments have been developed based on the JICA plan, introducing strategies that incorporate these new developments into account.

The JICA master plan was mainly focusing on the changes in the network system and the land use of the city, wherein most parts of Kabul city these changes were not applicable. The central government realized that for the green and sustainable growth of the city, we require to establish a vision for the future evolve of Kabul city in the coming years. For this purpose, in the year 2019, the Kabul Urban Design Framework (KUDF) was introduced (Figure 5b). The Kabul Urban Design Framework (KUDF) is a series of documents that aims to figure out how to use the existing potential of the city. They cover various topics that form the physical shape of Kabul: transport, accommodation, accessibility, and sustainability. The main difference between the JICA master plan and KUDF is in two major parts: first, it emphasizes the standard of urban design in the city. This has culminated in policies that fix regional problems but overcome them at the metropolitan level. The second difference is that the development strategies are proposed based on the existing city. The growth is viewed as expansion, rather than new construction in a satellite city, from the current urban fabric.

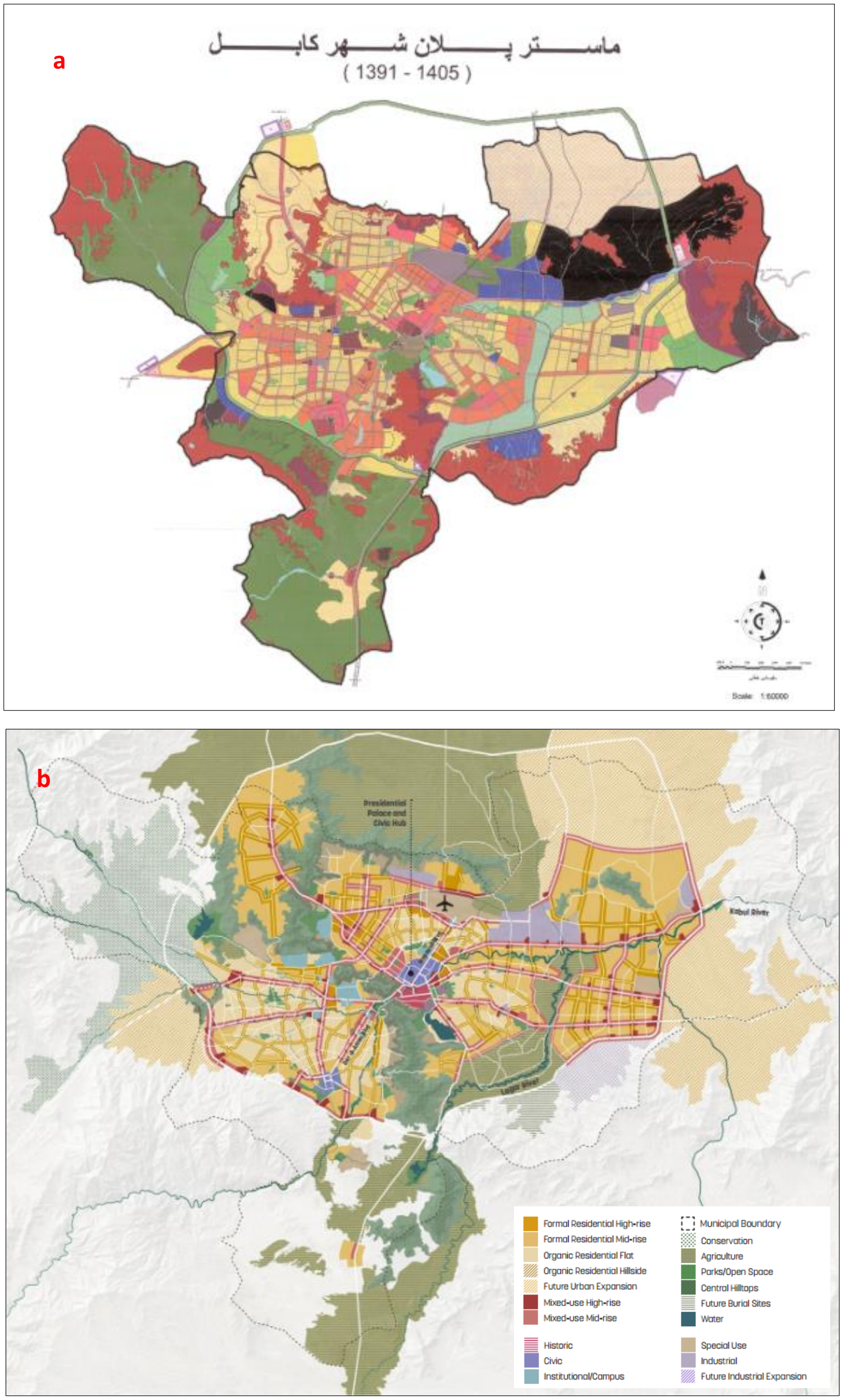


Figure 5: a) JICA master plan of Kabul year 2011, (Source: Kabul Municipality, b) Kabul Urban Design Framework (KUDF), Future development plan of Kabul, (Source: KUDF, Sasaki).

3.1.3. Dynamics of Informal Settlements in Kabul

Despite the violence and turmoil that the city has encountered, Kabul's population has risen exponentially in the past three decades. Returning refugees and migrants from other areas of Afghanistan, attracted to the city by economic opportunities and stability, were forced to develop their housing and neighborhoods (Sasaki, 2020). As the city grew rapidly beyond the scale envisaged in its 1978 master plan, these neighborhoods have expanded informally, absorbing a growing population according to individuals and community needs and resources (APPRO, 2012). In contrast, these informally developed neighborhoods lack the main factor that guides their development: the infrastructure, providing housing for the majority of Kabulis. They are an integral part of the city (Kabul Municipality, 2015). These informal areas will remain an essential part of Kabul, and it is required for the central government to acknowledge the existence and well define these areas, as well as integrate these areas in the development and planning process (Collier, Glaeser, Venables, Blake, & Manwaring, 2019).

In Kabul, informality is defined as houses and buildings built, 1) in violation of Kabul's master plan, and 2) without legal access to land (Collier et al., 2019). In the official context, informal settlements in Kabul are divided into two broad categories, 1) the settlements developed before the irruption of the war in 1978, and 2) the settlements developed after the war in 2001. After the year 2011, the informal growths changed the urban morphology of Kabul city (Yohannes Gebremedhin, 2005). Based on the morphological context, the development of the informal settlements in Kabul is shaped in different types of settlements, where the district, riverside, and escarpment are the most identified typologies of informal settlements in Kabul (Hussainzad et al., 2020). Functionally, informal settlements in Kabul have provided critical shelters where low-income people and families are granted 'right to the city in terms of low-cost housing. However, lack of tenure security, basic infrastructure, and public and social facilities are the challenges these settlements have in common (Sasaki, 2020).

In Afghanistan, informality is defined in two distinct ways: based on their land tenure and second based on their spatial characteristics. According to 'articles 2.1 to 2.10 of land tenure the regularization (Jahani, 2020), urban informality is divided into two parts; first, unplanned neighborhood and informality as individual plot (illegal settlements). According to this regularization, unplanned neighborhood "Sahat-e Ghair-e Plani" is defined as houses built on areas that are zoned as agricultural, non-residential, or restricted lands by the master plan. Still, the land is purchased from the real owner and received a formal or customary deed from the owner and recognized by the local government. The formal and customary deeds are recognizably based on Afghan land law. The illegal settlements "Zorabad" are defined as the house built illegally on the public or subdivided land that often does not fill the legal requirements for access to land.

According to the Kabul Urban Design Framework (KUDF), based on the spatial characteristics of informality, it is defined into three types; 1) informal settlements that are built-in core urban areas (figure 6a, b & c)., 2) informal settlements that are built-in hillside areas (figure 7d, e & f)., and 3) informal settlements that are built-in agricultural areas (figure 8g, h & i). Although every informally developed neighborhood has its own needs and characteristics, these types are defined by their common challenges, ranging from their accessibility and vulnerability to natural hazards and land tenure.

In compact, unplanned neighborhoods that have developed without organized utilities or facilities, where over 1 million people live (Sasaki, 2020).

Figure 6: Informal settlements developed in Urban areas: a) field visit photo, b) UAV image, c) topography map respectively .

In hillside dwellings, range from dense housing on the foothills to buildings built on steep hillsides, where around 700,000 people live (Sasaki, 2020)

Figure 7: Hillside informally developed areas: (d) field visit photo, (e) UAV image and (f) topography map respectively.

The informal settlements that are developed in agricultural areas are mostly concentrated alongside the Logar River, and across the city, different houses can be found as built-in packets, agricultural lands are being quickly transformed into residential (Sasaki, 2020)

Figure 8: Hillside informally developed areas: (g) field visit photo, (h) UAV image and (i) topography map respectively.

.

3.1.4. Local Policy Analysis of Vertical growth of Informal Settlements

The physical structure and architecture of a city are referred to as its urban form. It refers to a specific type of synthesis, an inductive process for identifying and organizing the main structural (form) components in built environments in a structural series (Walde, Hese, Berger, & Schmullius, 2014). While Kabul city continues to evolve vertically, the potential effects of vertical urban structure extend beyond sustainable growth; the built form affected the socioeconomic conditions, economic problems, sustainable development, and ecology of the city (UNDP, 2020). From a morphological standpoint, vertical urban forms with compactness are more likely to be sustainable because they have a higher population. Therefore, decreases overall housing supply-demand and informal growth (Dovey et al., 2020). Generally, sustainable development and urban form are inextricably linked to appropriate for the local context. However, Kabul's underlying vertical urban structure reinforces the increase in environmental, social, and transportation issues (UNDP, 2020). The uncoordinated densification vertical growth in the informal areas has exacerbated many of the current problems, resulting in overcrowding and poor service delivery. (CIAA, 2012).

Currently, there have been considerable changes in informal areas in Kabul city in terms of their physical structure and vertical appearance; informal houses are being constructed in the form of multistory buildings without any land-use rules and regulations (Sasaki, 2020). This rapid growth of informal settlements in the vertical form not only having accessibility, infrastructure, and better livelihood environment issues, but it also weakened the integration process of informal settlements due to its high density and compensation cost, absence of technical and social surveys, and resettlement issues (Kabul Municipality, 2015). In Kabul, many local factors drive the vertical growth of informal settlements since 2001. These factors have been identified by a review of many local policy documents, and these documents clearly describe the impacts of these factors on the vertical growth of informal settlements. These factors (Figure 9) are indirectly or indirectly linked together, as one aspect drives another.

The *first factor* that drives vertical growth is **population growth**. According to the CIA, 2021, the current birth rate of Afghanistan is 4.72/women, which is ranked 14th in the world (CIA, 2021). Joint family living is an Afghan tradition, it increases the number of families that drives those families to split their land parcel (Per Strips) or increase the number of stories because they prefer to live close to their parents or due to economic issues purchase new land. The *second factor* is **immigration**; there are three primary reasons behind immigration; 1) due to war or tribal conflicts which cause the development of IDP camps, 2) Politics that strives migration of different tribes, and 3) to access to economic centers. This immigration has already happened and still happening, but it has continuous impacts on the vertical dynamics of informal settlements in Kabul. In recent years, many IDP camps changed to permanent settlements due to the government's inability to provide housing, and these settlements continue to grow vertically. The political power in Afghanistan is mainly influenced by the same tribe or race communities, and many politicians keep their political power, encouraging people from their tribes to migrate to Kabul. So, they provide them with settlements by encroaching the public or private lands and illegally support them to build their houses in multistory. To access the economic centers' many people migrated to the city, and the lack of housing and high demand for cheap rents, allows the private landowners to build multistory houses for renting purposes in the informal areas.

The *third factor* that drives vertical informality is the **land market**. One of the significant differences between informal areas in Kabul and other cities in the world is that the informal areas in Kabul accommodated poor and mid-income class people. Because both classes cannot afford housing in the formal areas due to high land prices, and because of the low land prices in the informal areas, they prefer living in the informal areas. In recent years, it has become very common in Kabul that those who are unable to build their own houses choose private investors to build their houses. These constructions are illegally built by private investors as multistory residential, commercial, or mix-used buildings. This type of development has become one of the major factors in the vertical growth of informality.

Insufficient implementation of **plans and policies** is the *fourth driving factor* of vertical informality. Many urban development projects such as upgrading and so on, are insufficiently implemented, and after its implementation, the public services are provided un-collectively. It gives a sense of security to the residents of informal settlements against the future implementation of plans and policies. It also increases the land values in that area. So, the houses grow vertically without any hesitation and resistance from local authorities. In such circumstances, many residents rehabilitate or reconstruct their houses in multistory.

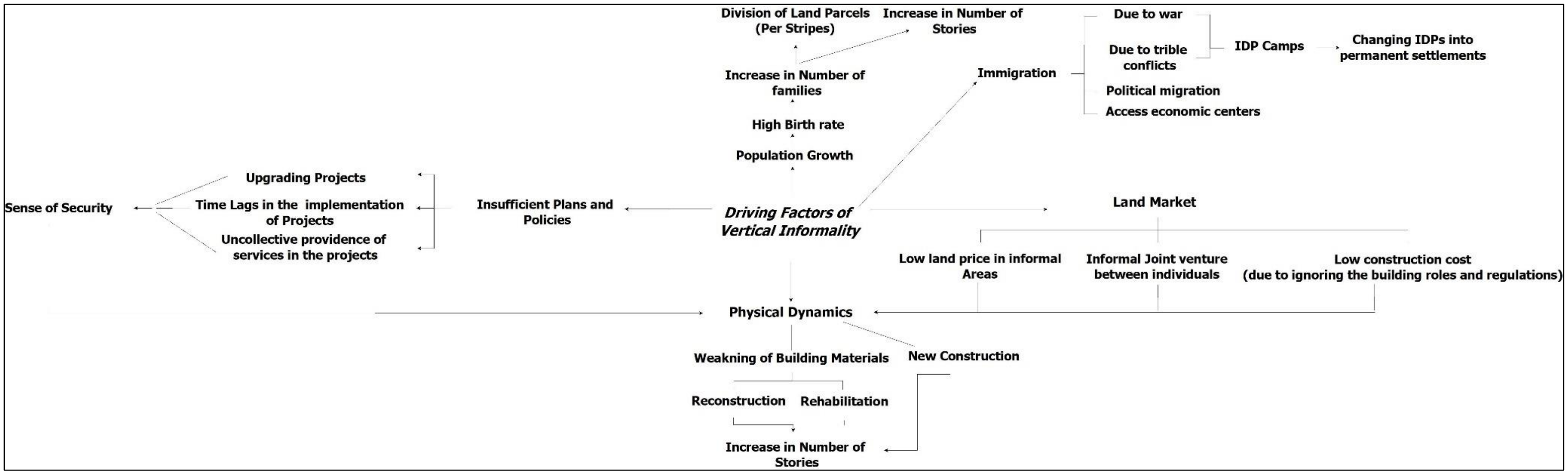


Figure 9: Mind map presents the driving factors in the vertical growth of informal settlements.

3.1.5. Case Study Site Selection

District 1 as a case study site is selected based on practical evidence on existence and growth informality and availability of the data. In our research, we have tried to understand the informality in the context of their physical characteristics and vertical growth, and their role in the current urban system of Kabul city. District 1 is in the center and presents the old city of Kabul. This district was established between the 1940s and 1950s, which is mainly located along Jada-i-Maiwand (Miawand road) (Kabul Municipality, 2015) (figure 20).

There are 23 neighborhoods (Gozars) in the district, and each neighborhood varies greatly by the number of houses, population, and areas. 65.3% of the district land accounts for the urban area, of which 46.6% is highly dense. Much of the eastern half of the district is suburban with strong cultural significance (Sasaki, 2020). In the 1978 master plan, the areas along the Jada-i-Maiwand were considered for commercial purposes but currently, most of the buildings have been developed for mixed-use purposes. The areas in the north and south sides of the road and till the foot of the hills have been developed informally as multi-story buildings/houses as residential and mix used. But the hillside areas are developed as residential (UNDP, 2020). Based on the referenced data (Un-Habitat survey data), most of the district's areas have been developed informally, except the two sides of Jada-i-Maiwand. More than 70% of people who are living in and around the hillside areas do not have any legal documentation that indicates possession of their properties, and they face inadequate living standards, in particular with issues such as water supply, solid waste disposal, and sanitation (Sasaki, 2020). Based on identified typologies of informal settlements in KUDF, the informal houses are on core urban and hillside areas.

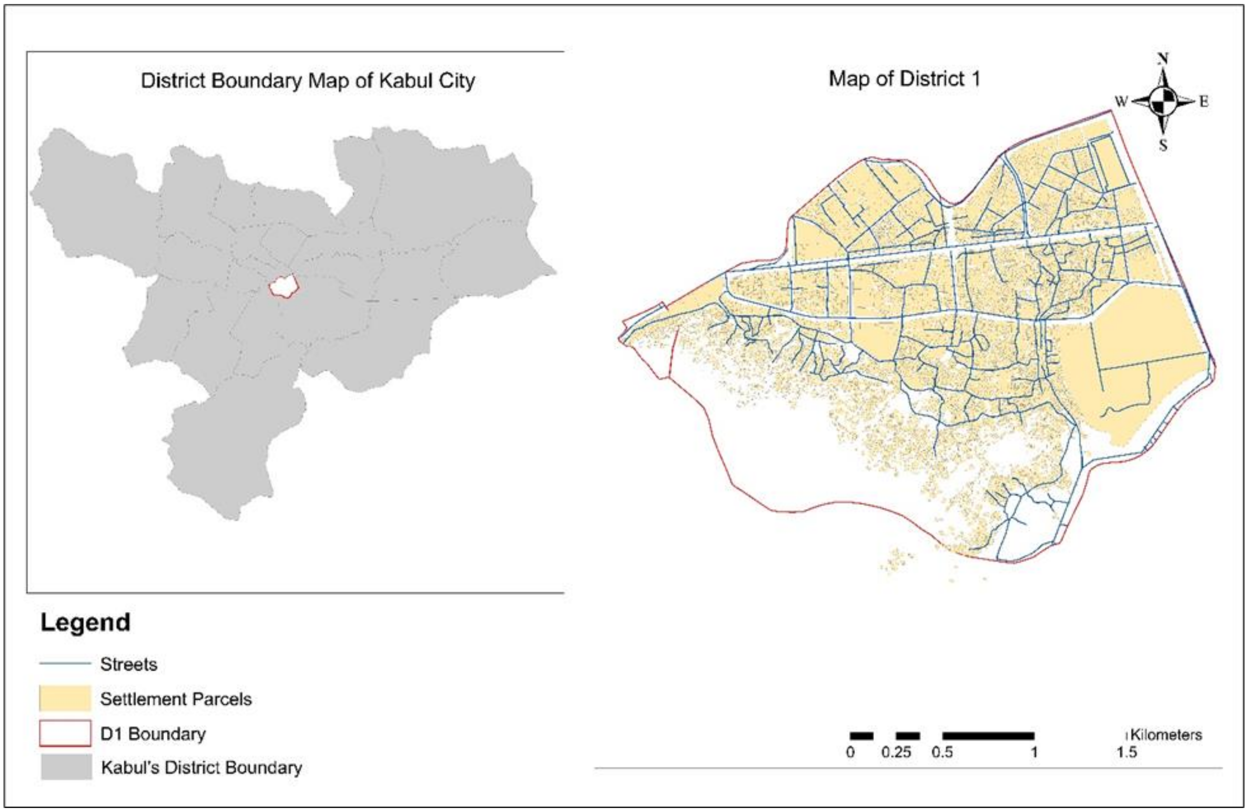


Figure 10: Location, boundary, and settlement map of district 1.

3.2. Overview of Methods and Data

To identify the vertical morphologies of informal settlement and to create a 3D model of these morphologies, the following are the three major stages for a systematic approach towards these aims of this study: stage 1, Identification, physical difference, and location factors analysis of vertical informality, stage 2, creation of the 3D model and stage 3, the assessment of the 3D data framework. However, various input data sets (EO data (UAV image), spatial data, and some other data from external sources), techniques, and logical relationships exist for the different phases. Figure 11 and Table 1 provide an overview of the workflow, input data, and methods used.

Table 1: Data information table.

Data	Description	Resolution	Year	Data Provider
UAV Image	No description	10 cm	2018	UN-Habitat
Feature class-shapefile	Land use is digitized by UN-Habitat GIS. The team in 2014/2015, this map is to be used for policy and knowledge purposes.	/	2014-2015	UN-Habitat
Spatial data	Dwelling Points and land plots are digitized by UN-Habitat GIS Team in 2014/2015, this map is to be used for policy and knowledge purposes.	/	2014-2016	UN-Habitat
MIS-data	The MIS-data contains parcel area, building type, building height, Building material etc.	/	2015-modefied in 2018	UN-Habitat
Land Cover (raster)	Generated five generic land cover classes (Urban, shrubs, grass land, Cropland, and sparse vegetation.	100x100	2021	Copernicus Global Land Service
Street map	Manually digitalized (District Level)	/	2021	Google earth
Tree points (Point class)	Manually digitalized (Block Level)	/	2018	UAV Image
DEM	No description	12.5x12.5 m	2018	Kabul Municipality
Concept Map (Feature class)	Concept map prepared based on defined land use in KUDF	/	2021	Kabul Municipality

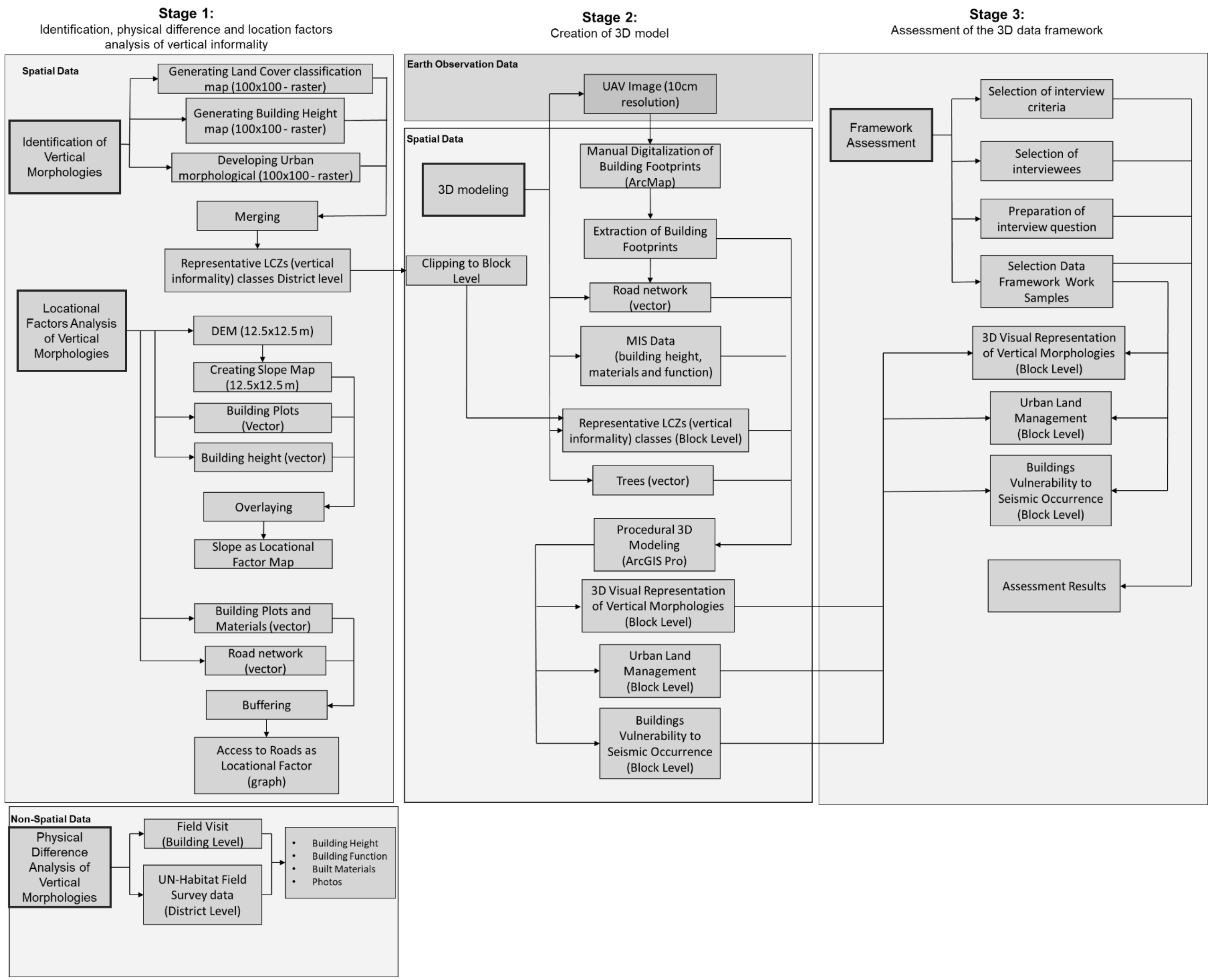


Figure 11: Work flow for developing of LCZ map and identifying types of vertical morphologies and 2D GIS database and pipeline for creating a 3D model of informal settlements ArcGIS Pro environment.

3.2.1. MIS Data

The MIS data type has been used as reference data that has been collected in a field survey by Un-Habitat as a part of the State of Afghan Cities (SoAC) program. The MIS data includes various information about houses in Kabul city, specifically in informal areas. Due to privacy issues, we had been able to access limited information of buildings such as their building height, use/type, material, land parcel area, and the number of the dwelling in Kabul city. For the analysis, the graph theory is used at the district level (District 1). The analysis will allow us to understand the physical differences of vertical informality based on their height and building height dynamics with relation to their land use and built materials. This data includes building height information of 6633 buildings in district 1. The household survey was conducted for the collection of this data at the district level, but many of surveyed houses lack the information needed for this study, only the above-mentioned numbers of houses included the required information. The spatial distribution and identification of the buildings are shown in (Appendix 1). In this data set, five types of land use such as governmental, commercial, residential, mix-used, and industrial, and five types of built materials such as modern concrete, concrete, masonry, local materials, and steel/woods are recognized and defined. Based on referenced data, the lands of district 1 are covered by 8% of governmental, 4% of mixed-use, 18% of commercial, and 69% of residential buildings. 3% of the buildings are built with modern concrete, 10% with concrete, 26% with masonry, 58% with local materials, and 2% with steel/wood. The formal buildings cover 4.5% of the district's lands and are concentrated along Maiwand Road (Appendix 1), and 95.5% of buildings are recognized as informal buildings.

3.2.2. Stage 1: Identification, physical difference, and location factors analysis of vertical informality

The proposed stage, will accomplish three objectives: 1) the identification of vertical morphologies, 2) locational factor analysis, and 3) and physical difference analysis. For the **first objective** '*identification of vertical morphologies,'* the Local Climate Zone (LCZ) classification method is selected. The LCZ provides a standard method for urban morphological studies, by categorizing urban landscapes into different LCZs based on urban structures. The is method is proposed by Oke & Stewert, (2012), which categorizes the urban landscapes into 10 built types and 7 natural types. For creating an LCZ classification map, the GIS-based method has been chosen. As other methods such as remote sensing and manual sampling need a comprehensive set of data planning, but the GIS method is more likely data-intensive. According to the data structure, and considering the geographical scale, the raster-based LCZ classification method is selected, as raster grids are a good fit for the LCZ classification system, which is intended to standardize vertical morphological observations and data reporting.

For the LCZ classification map, three types of raster data are used: the land cover, land plots, and building height. The land cover (100x100) classification map of district one is integrated into Copernicus Global Land Service, which includes delineated five generic land cover classes (Urban, shrubs, grassland, Cropland, and sparse vegetation). The building plot and height data are accessed from UN-Habitat. With the data mentioned above and the method, the LCZ classification map is created in four steps. In step one, the urban morphological map has been developed, in step two, a classification map is generated based on building height. In this stage, the land plots are considered as building surfaces, and in step three, a land cover classification map is generated.

At last, in step four, the generated maps are merged in GIS and developed LCZ classification map of district 1. However, the LCZ classification map is used to assess the spatial patterns of LCZ groups. For identifying vertical morphologies, a series of representative LCZ sites were chosen based on defined LCZ representative classes (Appendix 2).

The second objective is locational factor analyses of vertical morphologies. The analysis emphasizes the importance of the notion of location on the process of survival and growth in informal settlements by analyzing how location is one of the most essential factors in the growth of the vertical morphologies of informal settlements in the current urban patterns of Kabul. Two main locational factors have a high impact on the growth of these vertical morphologies; slop and accessibility to roads, both have been selected based on the actual and localized problems and topographic conditions that contribute to the dynamics of informal settlements in our study area. For the analysis, *the slope gradients* were calculated using an ASTER digital elevation model (DEM) with a resolution of 12.5 by 12.5 m. Each pixel is assigned to one of two topographic settings based on the DEM: foot slope and hillside. From this analysis, three direct impacts (distribution, density, and height) of slope on the growth patterns of vertical morphologies have been analyzed by visual interpretation. This analysis will show how the slope as a locational factor impacts the distribution, density, and height of the vertical morphologies within the study area.

The accessibility to the roads has been employed as *another locational factor* in the growth of vertical morphologies. The analysis has been done at the object level. The physical characteristics of buildings such as built materials and height were chosen as a parameter to analyze the patterns of vertical morphologies at certain distances from the roads. This analysis is done based on the notion that an increase in accessibility to the roads increases the vertical growth and the use of rugged construction materials. When accessibility to the road decreases, it decreases the vertical development and the use of hard material of informal settlements. To access the road data of district 1, Google Earth was used to digitize all roads open to motorized traffic and connected to the main job hubs of the district. However, in this analysis, the level of roads in terms of their use has not been considered. The building height and built material information are accessed from referenced data (UN-Habitat field survey). Both data are used as input in the GIS environment, and by using spatial buffering, the patterns of vertical morphologies have been calculated and shown in a graph.

For the **third objective** of stage 1, a case study approach with a triangulation data collection system and a mixed-method data analysis is adopted to identify the physical differences of vertical morphologies. Two types of data are used to complete this part of the study; primary and MIS data. *first*, the primary data is obtained from an on-site survey which the Upgrading Directorate of Kabul Municipality does by filling "Building information Sheet (Appendix 3) for each building/house surveyed in informal areas." This survey ended up with detailed information about the function/use, materials, and the number of stories of the informal building following the requirements, and took pictures. This data provided a piece of observative evidence about vertical morphologies in Kabul. The selection of the method was based on the parameters that differ these vertical morphologies from one another. These parameters are chosen by reviewing local policy documents (Land Acquisition Compensation Cost Bill) and MIS data. According to the local policy document and referenced data, three parameters (function/use, building materials, and building height) differ the vertical morphologies in the contexts of their physical characteristics. The local policy document recognized the four types of building function/use (residential, mix-used, commercial, and semi-industrial) and five types of built materials (Modern concrete, concrete, masonry, local materials, and steel/woods) in the informal areas. For which an observative analytical method is selected for their interpretation. The observative method is composed of an intensive observation study of these vertical morphologies. As mentioned before, the data for the study was received from the Upgrading Directorate of Kabul Municipality. The analysis results for this part of the study are shown in boxplots, including their median, interquartile distribution, and standard deviations. This tool can represent the disparity between groups and the variation between groups.

3.2.4. Stage 2: Creation of 3D Model

The workflow for the procedural modeling process for creating a 3D model is (Figure 9). This stage includes 2D GIS data preparation. for example, the extraction of building footprints, trees, and road networks. The second step consists of the building of a 3D model, which is implemented in ArcGIS Pro. Due to the high density and complexity of informal settlements of the study area, creating a geometrically accurate extraction of building footprints is a challenging task. The automatic approaches for detecting footprints of high dens and complex informal settlements require high image processing, which is time-consuming. Therefore, manual extraction of building footprints is applied for 1500 buildings by using a UAV image. The road network of the study area is digitalized from Google Earth, and because of the low number of trees, trees are also manually digitalized. This 3D model is developed based on the aforementioned 3D data method, as shown in (Figure 2).

The ArcGIS Pro is used to build the 3D model. The study area's elevation data of topography is taken from the global elevation model, and building height and other parameters such as built materials and building functionality data are accessed from digitalized MIS data, building footprints. Tree locations are taken from the 2D GIS database. This 3D model is created primarily by extrusion at LoD1 and is deemed a basic 3D model easily created for most cities with 2D GIS data available. The purpose of using GIS extensions for building the 3D model is that the platform provides more realistic features, and it is considered the best tool for procedural 3D modeling.

This part of the study's aim is to transform the spatial information into 3D geo-visualization through a novel and simple method to effectively assist information sharing and decision-making. Three types of analysis are driven by the integration of the 3D data framework:

- *The 3D visual representation of vertical morphologies,* the 3D data method is used to visualize the identified vertical morphologies in terms of volume or floor space to examine their outward and upward patterns and influence on their urban forms in the study area.

- *Representation of spatial information for urban land management,* this part of the analysis focuses on the use of this 3D data method for the visual representation of urban space and future urban planning of informal settlements. The 3D data method for interactive urban space determines the level of geographical condition elicited by the visual. In practice, urban design practices are concerned with the physical development of the built environment's fundamental components, such as buildings, streets, and landscape features. The second use of this method is the representation of urban planning. In the study area, several planning processes have taken place and continues. So far, one type of plan (concept plan) is examined. With the integration of this method, changes in three-dimensional space are examined. How the area will be affected and what will change with the implementation of the concept plan.

During the integration of the 3D data method, several recurrent observations are made: preparing interactive 3D models often necessitates substantial and time-consuming data pre-processing; there is frequently a trade-off involving realism and interaction. Planning applications in an urban context can use 3D modeling to considerably reduce development efforts and costs. For the integration of the 3D framework in the urban planning application, one of the study area's development plans (concept plan) has been examined, which is accessed from Kabul Municipality. This plan includes the examination of future changes in the current condition in the 3D model space. In contrast to EO data, the plan chosen for integration was not georeferenced and could not be immediately integrated into the 3D city model. Furthermore, plan objects, such as the number of stories in a proposed building, were contained in CAD files rather than attribute tables. As a result, many pre-processing procedures were required to generate 3D visualizations from the examined plan. When only CAD files were available as source data, the data needed to be georeferenced and scaled, and features to be digitalized before further creation of the models.

- *Buildings vulnerability to seismic occurrence,* physical and social elements are the variables that can be impacted sensitively by seismic occurrences. In many cases, the 2D mapping is used to reflect both physical and social aspects of vulnerability. This 3D data method can also be used to support urban risk management and decision-making. The method is used to visualize the damage and vulnerability levels of the buildings in terms of their built materials, height, and topographic location due to seismic occurrence.

With the proposed 3D data method application, a 3D seismic vulnerability model is created, which is built for the whole study area. The vulnerability model provides information, which reveals the degree of possible loss at each location due to a given hazard. Many social and physical factors contribute to urban vulnerability due to seismic occurrence. Here, the focus of the study is on physical factors such as soil, topography, geology, built materials and land cover, and so on. Only two factors (built materials and topography) are considered in creating a 3D vulnerability model from the available data. As most houses in the informal areas are built with local and masonry-type materials, their topographic condition with the historical seismic event in Kabul increases the level of vulnerability of the houses due to this hazard. The damage degree of each habitation is classified based on two factors: the overall building vulnerability index, and their topographic location.

The building vulnerability index values are taken from Afghan seismic code levels (e.g., the building vulnerability index value of local materials is highest and masonry-type materials are the second-highest and modern concrete is the lowest). In the layers corresponding to these two factors, the building's geometries are created, and they are given a solid color that match corresponded to the damage degree. Six different colors are assigned to the damage degrees based on the European macro-seismic scale (EMS98) damage degree definition. The damage degree 1 indicates the lowest damage, degree 2 trivial damage, degree 3 partial damage, degree 4 partial collapse, and degree 5 total collapse. The houses are assigned in the group of degrees based on material and slope changes. For instance, houses in very steep slopes (40 to 53 degrees) and built with local materials are assigned as degree 5, and the houses built on the slope of 30 to 40 degrees are considered degree 4.

3.2.5. Stage 3: Assessment of 3D Data Framework

One of the aims of this study is to propose a generic 3D data method to be as feasible as possible for urban planning purposes. This should accomplish by involving urban planning practitioners and also relying on the opinions of the experts. The framework underwent through the critical assessment of practitioners and experts. The practitioner's group was chosen from the urban planning department of Kabul Municipality, which is responsible for planning and managing the urban projects in Kabul. The expert group was selected from freelance urban planning practitioners and technical advisors. First, for all groups, the topic is briefly introduced and then interviewed. The interview was structured as: each group is interviewed separately, the members of each group, were asked about their professional opinions and the results are discussed within the group. In the end, the results of each group are summarized as a group and then narrated. The interview questions are shown in (Appendix 4).

4. Results

In the below sections, the types of vertical morphologies are identified, and the main factors that differentiate these morphologies in qualitative and quantitative manners are presented. Moreover, the main implications of 3D modeling over the visualizing and evaluation of patterns of these vertical morphologies of informal settlements are analyzed.

4.1. Sub-objective one: To identify the vertical morphology of informal settlements in Kabul.

These sections obtain the results of the analysis for identifying the types of vertical morphologies, their physical difference analysis, and locational factor analysis of morphologies. furthermore, the results are obtained in observative (visual interpretation and field visit) and quantitatively (graph theory) manners.

4.1.1. The types of vertical morphologies

Land surface conditions of district 1 exhibit considerable diversity in land cover forms and building types, as cl early demonstrated by the LCZ classification map (Figure 12). The LCZ E class occupied a significant percentage of the land surface of District 1, as these areas are mainly located in the central, west, and northeast parts of the district. These areas are considered as highly urbanized areas of the district, where the majority of built-up areas of the district are dominated by compact low-rise (LCZ 3), compact mid-rise (LCZ 2), and lightweight low-rise (LCZ 7) building types classes.

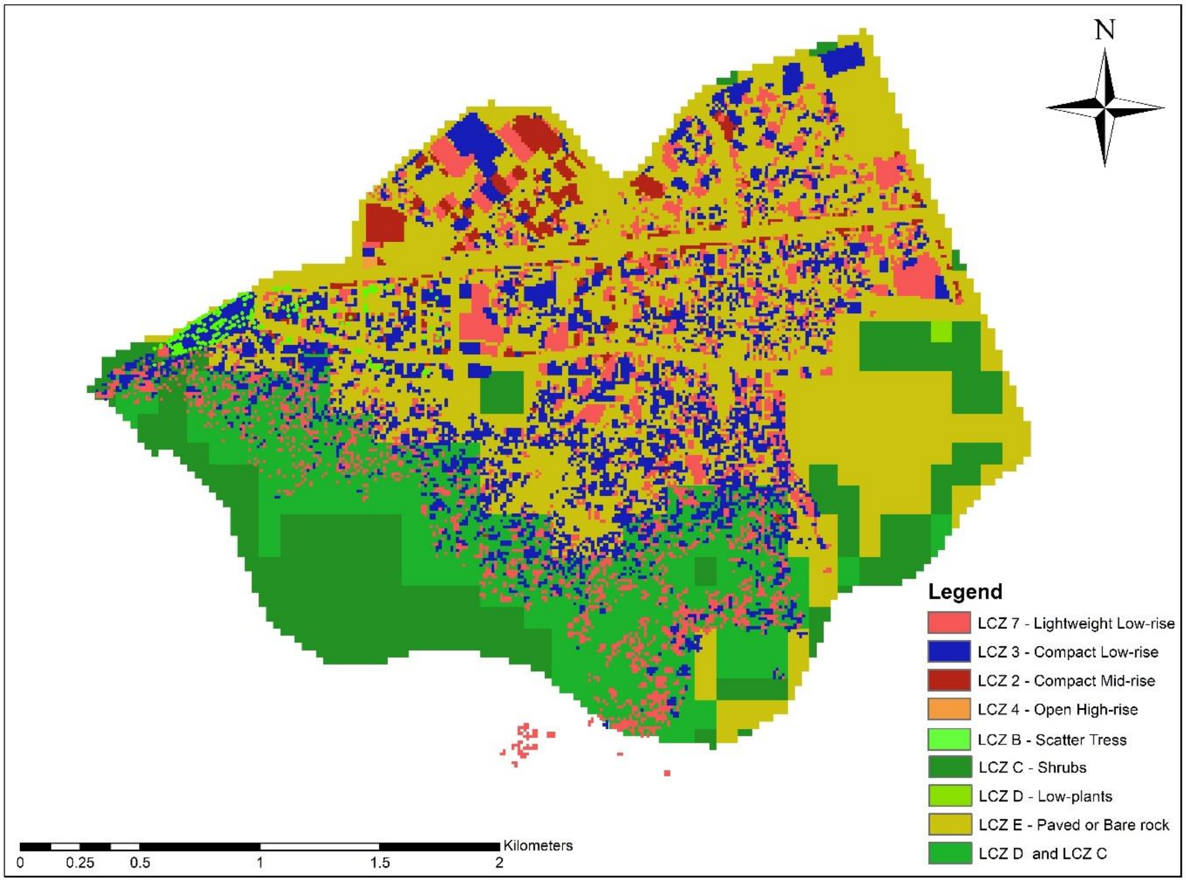


Figure 12: District Level LCZ (vertical morphologies) classification of District 1

Figure 12, shows the urban structure typologies in the context of building forms, only four of the classes, such as "open high-rise (LCZ 4), compact low-rise (LCZ 3), compact mid-rise (LCZ 2), and lightweight low-rise (LCZ 7)", classes were found. Other remaining classes such as compact high-rise (LCZ 1), open mid-rise (LCZ 5), open low-rise (LCZ 6), large low-rise (LCZ 8), sparsely built (LCZ 9), and heavy industry (LCZ 10), were not found. The compact low-rise is highly clustered in the central parts of the district, and the compact mid-rise can be found along and surroundings of the Maiwand road. The LCZ classification map provides us a summary of urban structure types in district 1. According to the MIS data, 95.5% of the district buildings are developed informally, and according to the building level, these four urban structure types (LCZs 2, 3, 4, and 7) demonstrate existing types of vertical morphologies of informal settlements. In conclusion, we can illustrate that compact low-rise, compact mid-rise, and lightweight low-rise represent the types of vertical morphologies of informal settlements in district 1.

For analysis and evaluation of vertical properties of the vertical morphologies under a high-density scenario of the study area, the collection of typical classes of LCZ2, 3, 4, and LCZ6 were selected based on the LCZ classification map. Since raster grids cannot precisely define the borders of building features, it is vital to choose typical classes in district 1 for determining the LCZ urban structure types (Figure 12).
As a result, visual interpretation was used to verify vertical morphologies' shape, size, and aggregation patterns in the LCZ grids. In line with the representative examples seen in Stewart and Oke's (2012), analysis, a series of standard LCZ grids with comparatively heterogeneous Stewart and Oke (2012), defines the urban characteristics of selected classes as follow: the LCZ 2 class is consist of midrise buildings (3–9 stories) in a dense cluster. There are few or no trees. The land cover is primarily asphalt—construction materials such as stone, mortar, tile, and concrete. The LCZ 3 class is a densely packed collection of low-rise (1–3 story) buildings. There are few to no trees. The land cover is primarily asphalt, and construction materials such as stone, mortar, tile, and concrete are used. For class LCZ 4, a tall building with tens of floors in an open arrangement. Pervious ground cover is abundant (low vegetation, scattered trees). Building materials include concrete, steel, brick, and glass, and they define LCZ 7 class as a densely packed collection of single-story buildings, with few to no trees. The land cover is primarily compacted and Lightweight building materials (for example, timber, mud, stone, and corrugated metal).

By the visual interpretation and available data (MIS data), the findings are largely consistent with the LCZ figures developed by Stewart and Oke (2012), except for one variation in the LCZs of open High-rise zones (LCZ 4). The main difference lies in the number of buildings in the area; there are only two buildings with 14 and 10 stories within the study area. The other remaining buildings' number of stories varies from 1 to 9 stories.

4.1.2. Physical Difference Analysis

When it comes to physical differences of vertical morphologies of informal settlements in Kabul, three major parameters exist that differentiate these vertical informalities: the first parameter is the functionality of buildings, the second is the built materials, and the third parameter is the building height. These parameters are identified and defined based on the local policy document (Land Acquisition Compensation Cost Bill) and UN-Habitat field survey data (MIS data). In the local document four types of building functionality (residential, mix-used, commercial, and semi-industrial), and five types of built materials (modern concrete, concrete, masonry, local material, and steel/wood) are used in the construction of buildings in the informal areas are mentioned, and the results based on these two parameters are presented qualitatively. The results for the third parameter (building height) are presented as graph theory.

Physical Differences based on Building Functionality

The main building functionalities of vertical morphologies of informal settlements in district 1 are residential, mix-used, and commercial, most of these buildings are built without any legal permit and without considering the building rules and regulations.

The first functionality that defines one type of vertical informality is the residential use of buildings. These buildings are built in different configurations: the single unites houses surrounded by the walls as a property boundary (security and privacy reasons) and vertically oriented from 1 up to 7 or 8 stories, where the number of stories is closely related to their built materials and use (Figure 13a). One of the most common configurations of multi-story residentially used buildings in the informal areas is the single house as residential apartment style. These types of buildings have two entrances that are faced to the streets and are built as an apartment-style to fulfill the needs of a family (an increase in the number of families) or for renting purposes (Figure 13b). The residential buildings built with a legal permit in the formal areas but built with low quality and do not fulfill the requirements of architectural and building codes are other types of residential buildings that, according to land and building control regularizations, are considered as formal-informal buildings. (Figure 13c).

The second functionality of vertical informality is the mix-used buildings. These forms of buildings are mostly built along the main and secondary roads of informal areas. The first story of these buildings is used as commercial, and the second to third stories are mostly used as offices, private clinics and schools, and storage, where the number of stories of these buildings reaches from 3 to 10 stories (Figure 14a). There is another type of mixed-used buildings built along the main roads of informal areas with a legal permit but currently used for another purpose. Most of these buildings are used as private hospitals, schools, and offices, according to article 14, chapter 2 of building control regularization, these buildings are considered formal-informal buildings (Figure14b).

According to MIS data, commercial land use is the third category of land uses in informal areas of Kabul. Generally, inside the dense informal areas (areas with narrow streets and low accessibility), semi-commercial activities such as grocery and retail shops, bakeshops, and informal parking lots are common. These activities are running on the first floor of 2 or 3 stories houses faced to the streets (Figure 15a, b & c). Major commercial buildings are clustered firstly in the crossroads and secondly along main arterial streets throughout the informal areas. Shopping centers and offices are also comprising other common building uses of commercial buildings.

Figure 13: Typologies of residential buildings, a) single unit house, b) apartment style informal residential building, and c) formal-informal residential building

Figure 14: Mix-used informal building typologies, a) informal mix-used typology, b) mix-used formal-informal typology.

Figure 15: Commercial use of building in informal area, a) one story commercial use, b) 2 to 3 stories commercial use.

Physical differences Based on Built Materials

According to a local policy document in Kabul, these five types (modern concrete, concrete, masonry, local materials, and steel/wood) are common building materials that have been used in the constriction of buildings in the informal areas. The built materials are one of the parameters that differentiate the vertical morphologies in terms of their physical characteristics.

In the informal areas, the use of modern concrete materials is limited to governmental buildings, including district offices, clinics, water supply station buildings, district police stations, etc. It is very rare to find the use of this material in the construction of informal houses. This material is commonly used in formal areas, especially in the construction of mixed-use buildings, apartments, and industrial purposes. The central government announced that it is prohibited to provide any information about governmental buildings due to security restrictions. So, for this reason, we were not able to complete fieldwork for governmental buildings.

The houses are built with local materials; they combine stone, mud, and wood. When people use local materials or masonry to build their houses, they use stones in the foundation of surrounding walls and rooms. The roofs of these houses are flat and constructed with wooden posts and then covered with a combination of mud and straw (Figure 16a, b & c). These houses are surrounded by walls built with mud to offer protection and privacy (Figure 16d & e). Typically, this occurs very frequently in informal communities where accommodation is a major concern. Vertically these types of houses reach one to three stories, which depends on their geographical locations.

The houses built with masonry-type materials can be found in Kabul city, specifically in the informal areas. The configuration of houses with these types of materials is a combination of modern and traditional architecture. The surrounding walls are made of bricks and stones with cement, and the interior and exterior walls of the main building are made of bricks. The shape of the roof is flat and built with steel girders, wooden timbers, or bricks (arched between two rafters) and covered by concrete (concrete without steel rods) (Figure 17).

In Kabul, houses that are built with concrete are widely available throughout the informal areas. In several neighborhoods, you can find multi-stories concrete houses that have used modern and traditional architecture. The shape of the roof is mostly flat, and sometimes mansard roofs can also be found. The surrounding walls are made of stones (in the foundation) and bricks and covered with PCC (Plain Cement Concrete) or decorative bricks and cinder blocks. The structure of the houses is built with RCC (Reinforce Cement Concrete). Still, the interior and exterior walls are covered with bricks, and PCC is used to cover exterior walls and stucco for interior walls. The concrete-type materials are used for houses and have high use in the construction of commercial and mixed-use buildings. The only difference in materials is the covering materials for the façade, where the titanium-cladding panels and steel-framed are mainly used for the finishing part of the buildings (Figure 18a, b & c).

Figure 16: Local material-built typologies, a) one-story single unite house, b) common roof typology, c) number of flloor based on location, d) local materials built surrounding wall, e) room side location

Figure 18: multi-story masonry-type material house in informal area.

Figure 17: Informal houses built with concrete, a) multi-story concrete house, b & c) structure details of concrete material

Physical differences Based on Building height

Another physical difference of identified vertical informalities is the building height. For the analysis, the land use, built materials and building height are used as parameters. The results of changes in building height with the dynamics of land use and built materials are analyzed. Beyond an observative description of the physical condition of the vertical informality, these spatial and physical parameters will give us more detailed information about their vertical patterns and variance at the district level. The analysis will show how the vertical pattern changes concerning land use and built materials.

The district level does not show an equivalent vertical development concerning building materials. Consequently, the high variance of the building height based on built materials confirms the result's incongruity. According to the results, the heights of the 50% of buildings built with local materials and masonry do not seem to extend from 2 stories, the remaining 25% of buildings are one story, and the other 25% of buildings are 2 to 3 stories. The building is built with concrete, 50% of the buildings are from 2 to 5 stories, 25% of buildings are 1 to 2, and 25% of buildings have 5 to 9 stories. The height of all buildings with steel/wood does not extend from one story, but buildings with modern concrete have a high number of stories compared to other materials. Most of the buildings with this material have a height from 3 to 7 stories, and the one minor part of the data shows the extension of heights of these buildings from 7 to 10 stories, and other miner part shows the height of these buildings from 1 to 3 stories (Figure 19).

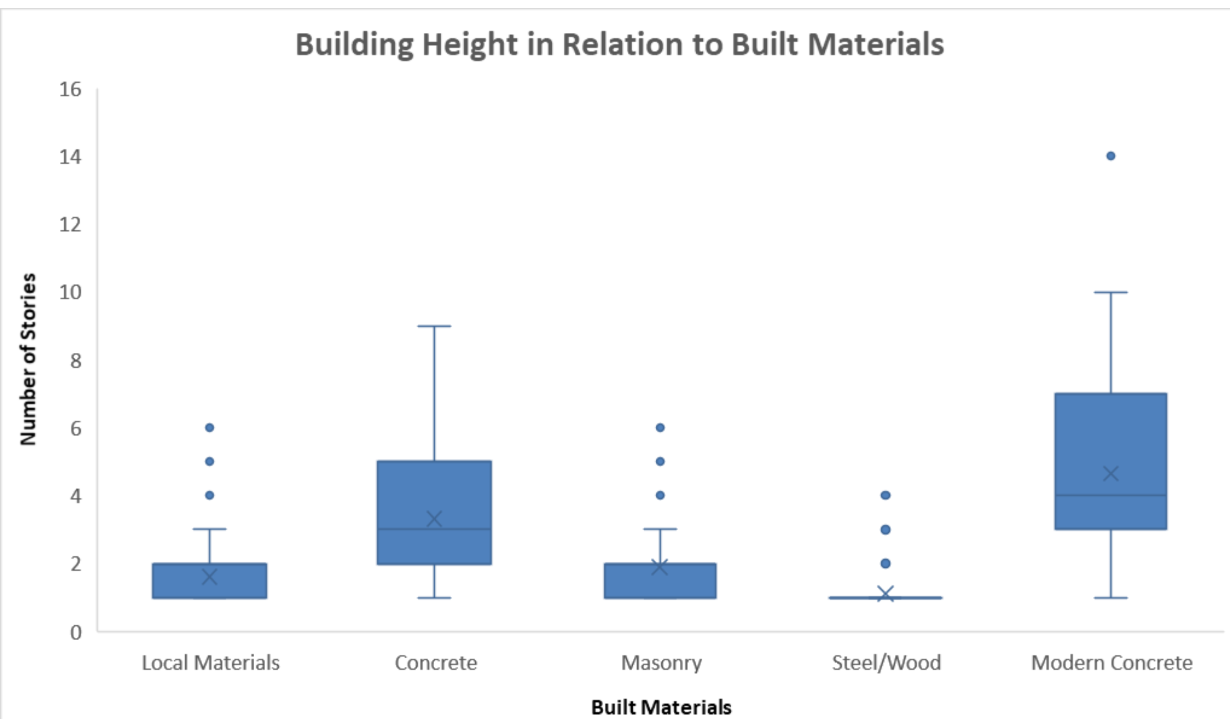


Figure 19: Building height dynamics in relation to build materials.

The traditional land use and its forms of development have been a significant determinant of the growth of vertical informality in district 1. The land use of the study area has been developed by human needs connected to the activities such as residential, commercial, mixed-use, and industrial considerably altered the vertical patterns of informal settlements. Residential land use is dominant in the environment of informal settlements of district 1. The morphological patterns of the district show that the distribution of residential land use is more fragmented compare to other land uses, which are highly concentrated in more accessible areas. In the areas with better accessibility, the distance between buildings is shorter and even adjacent to each other in all land uses than low accessible areas. The results in figure 20 indicate a high variance of heights of the buildings with consideration of their land uses. Almost 100% of the governmental and total number of industrial buildings in this district are one story. The 50% of residential buildings' height varies from 1 to 2 stories, and 25% are all one story, and 25% of buildings have 2 to 3 stories height. A high percentage of mixed-use buildings have 2 to 3 stories, but some of the buildings have 1 to 2 and 3 to 4 stories in height. For the commercial building, 25% of buildings in this district are one story, 50% have 2 to 4 stories height, and 25% of other buildings are 4 to 8 stories.

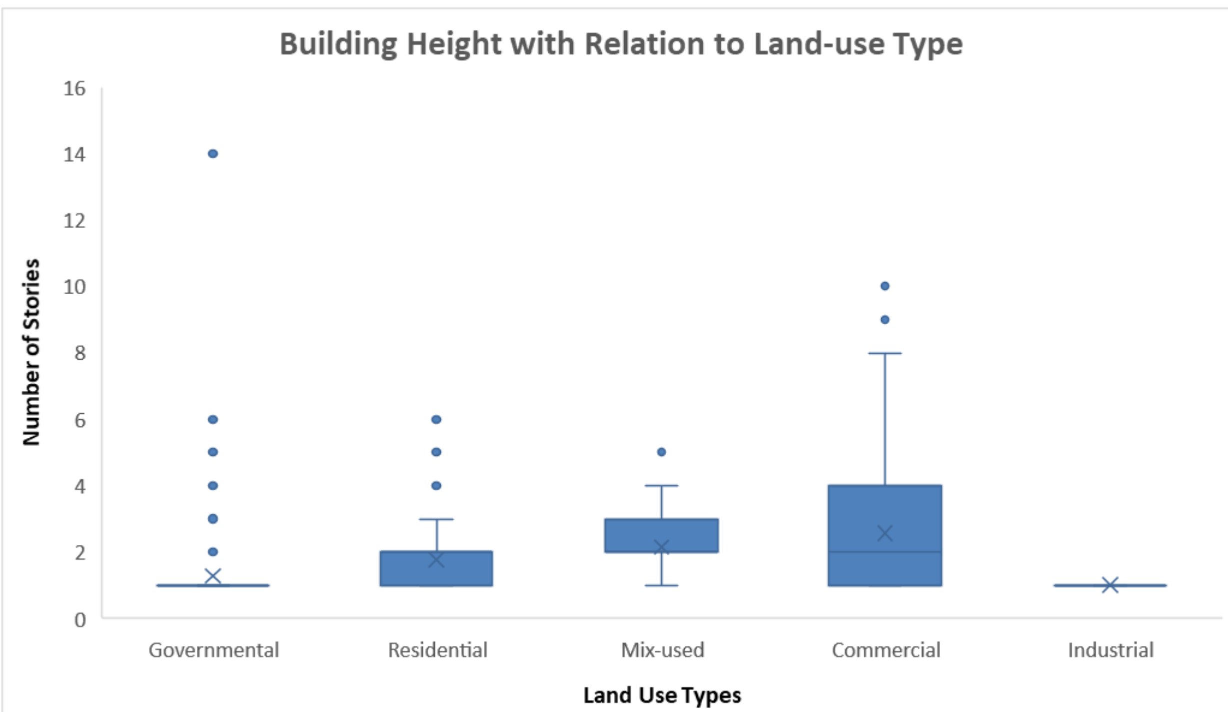


Figure 20: Building height dynamics in relation to land-use typologies.

From the analysis results from both figures, we concluded that there is a relationship between land use and built materials with the vertical growth of informal settlements. Based on the needs of the residents, changes in land use happen without any intervention of plans and policies. These land-use typologies select a base for the use of building materials that bring up variation in the physical characteristics of informal settlements' vertical growth. In conclusion, the buildings that used hard materials in the construction have the highest number of stories, and the use of local/masonry materials in the buildings shows the low number of stories of buildings. The commercial and mixed-use buildings have a high number of stories in comparison to other land use typologies.

4.1.3. Locational Factors Analysis

The lands that are occupied by the informal settlements in Kabul are generally less suitable for urbanization than other parts of the city, as their emergence is in flood-prone (riverside), high-slope, and landslide-prone (hillside) areas. This ultimately resulted in uncontrollable fragmentation of lands, such as sub-division of land parcels and small-size housing, and, in some cases, the transition to compacted informal growth, especially in the inner parts of the city such as district 1. This means that the building footprints are maximized, and minimizes the accessibility to the roads, and changed the patterns of the settlements in terms of their height, use, and types of materials in use.

Slope as a Locational factor

Figure 20 shows the slop condition of district 1. Foot slope areas are the highest topographic class in this district, which comprise 55.4% of the whole study area and 68.3% of the built-up of the present day. The hillside areas form 44.6% of the whole study area and comprise 31.7% of the built-up area of the district. The slope of foot slope areas varies from 0 to 11 degrees, and built-up hillside areas developed on land with 12 to 51 degrees slope. The slope directly impacts the development of informal settlements in three different aspects: their distribution, density, and height. If we compare the settlements of foot slope and hillside areas in terms of their distribution; in foot slope areas, houses are constructed in the direct neighborhoods and adjacent to each other in the shape of series, tried to build the houses near roads for better accessibility. Unlike foot slope areas, the distribution of the settlements in hillside areas has resulted from the pushed process; the settlements are pushed to the locations that have the least suitability for building a house. As shown in figure 21, in the lower slope, houses are built in the shape of a small pocket of the land but, with the increase of slope, houses become more distanced (lower density).

Another impact of slope on informal settlements in Kabul is on the density. The density of the settlements in the hillside area is 14 houses per hectare and in the foot-slope area is 24 houses per hectare. An increase in the slope patterns limited the accessibility and vertical growth of informal settlements. However, the trade-off between dwelling space, transportation space, public and private open spaces, and public facilities are the challenges that both areas have in common. Many related sectors were unable to control the vertical growth of informal settlements, but slope does. As slope decreases accessibility and vulnerability to environmental risks, it limited the vertical growth of informal settlements in Kabul. From the figure, it can be interpreted that there is a decrease in vertical growth with an increase in slope gradient. Most of the houses built in hillside areas, specifically in areas with a steep slope, are one story and in the second two stories, and as far the smother the slope goes, the vertical pattern changes in higher stories.

Figure 21: slope impact on distribution, density, and vertical patterns of informal settlements.

Accessibility to the Roads as a Locational Factor

Figure 22 shows the relation of the built materials of informal settlements due to the changes in road accessibility. The figure shows a great variance in the use of materials by increasing distance from the roads. At a distance, 10 to 200 m from the road (measured from the centerline of the road), from 200 m till above distances the results do not show any changes, therefore, we limited our maximum distance to 200m. The results show a gradual decrease from 4.2% to 3.1% in the use of modern concrete. The same results have been derived for the use of concrete and steel/wood, both decreased from 11.7% to 9% and 3.2% to 2.7%. The use of masonry materials in the construction of informal houses was 27.5% within 10m from the roads, and there was a slight increase in its use within 20m to 50m distances by 28.6%. Still, again it decreased drastically to 26.8%. The proportion of houses built with modern concrete, concrete, masonry, and steel/wood decreases with an increase of distance from the roads, but it is not the case with houses built with local materials. The percentage of these houses increased from 53.3% to 58.4%, which means the closeness of the houses to the roads provides better accessibility and increases the land values. Thereby, it pushed the people to the lower accessible locations within the district. In conclusion, we can say that most of the houses with the lowest accessible areas are built with local materials.

As in figure 19, we showed a relation between the height of buildings with their built materials, and from the results of the analysis, we can interpret that the buildings that are built with rugged materials (modern concrete, concrete, and masonry) are highly concentrated within 10 to 50 meters from the roads. The number of stories of these types of buildings various from 3 to 14 stories, as long as the use of these materials decreases by the decrease of accessibility to the roads, it affects the vertical growth of buildings such as houses built with local materials where their number of stories highly various from 1 to 2 stories. In conclusion, this analysis clearly showed that accessibility to the roads performed as one of the controlling factors in the growth of informal settlements, where it not only controls the dynamic of the buildings in terms of their built materials and use but also controls their vertical growth.

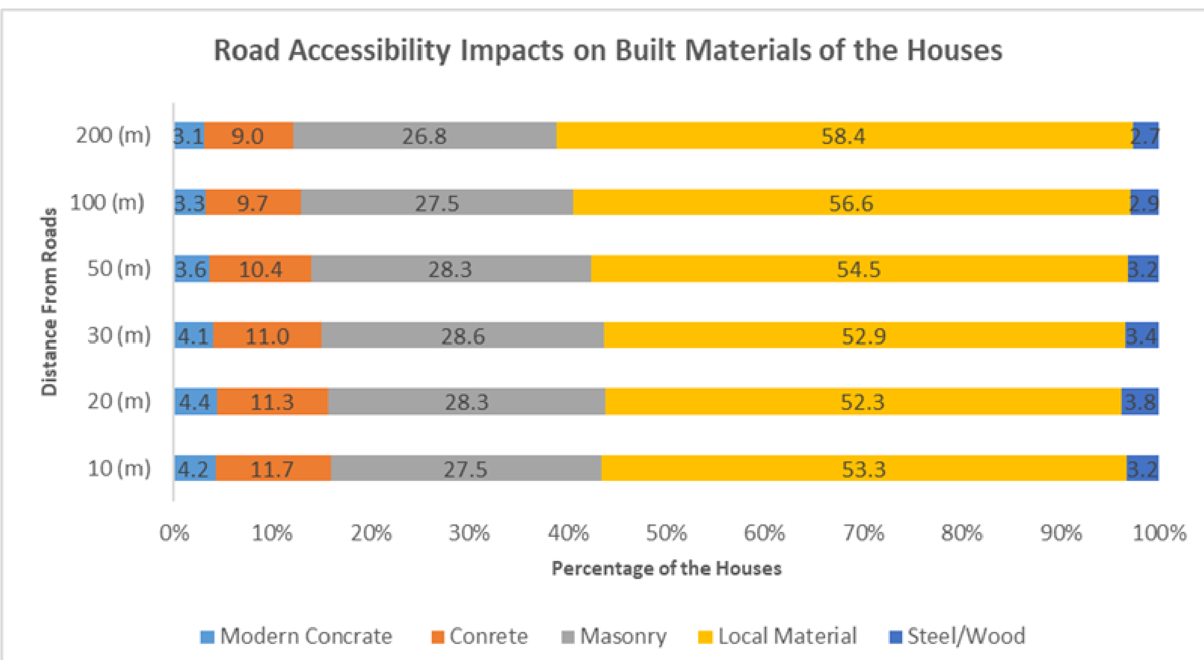


Figure 22: Road accessibility impact on bult material and vertical growth of informal settlements.

4.2. Sub-objective 2. To investigate 3D data methods and creating a 3D model to analyze the vertical patterns of informal settlement.

This part of the analysis so far focuses on the integration of visual representation of vertical morphologies of informal settlements into a 3D data method at the level of Details 1. Through this 3D visual representation, many spatial and physical characteristics of the vertical morphologies and how these vertical morphologies are distributed, are analyzed. For the integration of the 3D data method, the vector features are directly integrated.

4.2.1. The 3D visual representation of vertical morphologies

Figure 23 shows the manual classification of vertical morphologies in 3D at the block level. This model is attributed to parameters such as building height, volume, and structure typologies based on LCZ representative classes. This three-dimensional visualization of structure typologies of vertical morphologies also indicating their topographic location, spatial distribution, and density. The 3D model shows a significant physical difference between these morphologies. The LCZ classification map (Figure 12) shows land surface conditions in the study area are pretty diverse considering land cover and building types. However, the 3D model offers three LCZ classes of building types (due to the spatial coverage of the model) and one land cover class (LCZ B). The hillside (steep areas) areas are highly dominated by LCZ 7. Still, most of the study area is covered by class LCZ 3. from visual interpretation, it became obvious that taller building structures with lower built-up density and larger building volume are concentrated along the main roads with better accessibility. In terms of distribution, smaller building structures are highly distributed than taller ones, especially in hillside areas. The distribution and structure patterns of these vertical morphologies determine the heterogeneity in their physical term.

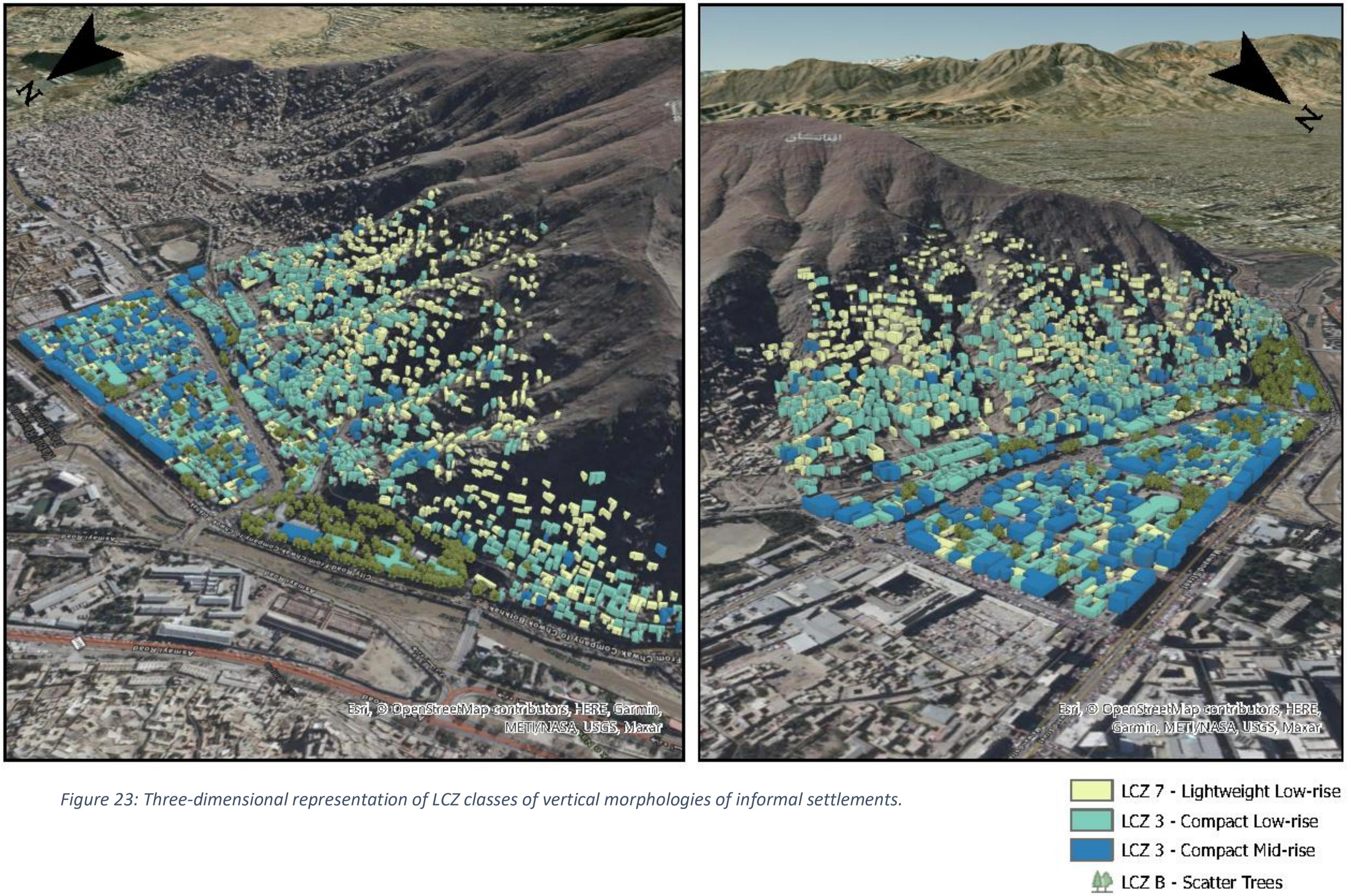


Figure 23: Three-dimensional representation of LCZ classes of vertical morphologies of informal settlements.

4.2.2. Representation of spatial information for urban land management

In the context of 3D city modeling, advancements in EO technologies, as well as data processing, have led in methods to manual and (semi-) automatic processes for the derivation of 3D city objects and models. As a result, the cost of creating 3D city models has steadily decreased. In comparison to EO data integration, the integration of heterogeneous spatial information for land management as a 3D plan representation necessitates additional data processing. This is especially true if the sole source material accessible is Adobe PDF documents or pictures, and data in other formats. The followings are interactive block models that have been merged with terrain textures drawn from the real condition. The 3D modeling results represent more geometric and visual details of the existing condition. The representation of information for land management and urban planning, this part of the study focuses on two themes: first, the use of the 3D data method for the visual representation of urban spaces, and second for future urban planning.

The urban space is represented in terms of its built-up location, road accessibility of hillside houses, and street patterns. Figures 24a & b show the overall topographic, land division patterns, and built material dynamics of vertical morphologies. Figure 24a shows the alignment of built features and natural features. In the topographic context, the houses are built in foot slopes and hillside areas, and there are no green spaces except some scattered trees. The 3D view also shows that how the houses are spatially distributed based on their geographic location. Hillside houses are more dispersed than foot slope houses. From the interpretation of figure 24b, there is a high variance of building materials in both foot slope and hillside houses. The use of concrete materials in foot slope areas can be seen more than in hillside areas. The hillside houses in the study area are low technology products, use of local materials, self-help and local labor, traditional building skills, and basic equipment. With certain variations in the use of materials, houses on hillsides are the copy of rural houses for residents and builders. The houses on the hillsides are very small. Areas with a lower slope near the foot plains with better accessibility, houses with 2 to 4 stories are built with one of three types of materials (concrete, masonry, local). However, in the steep areas, most houses are built single-story or a maximum of 2 stories rectangular units, built with local materials, and have a very simple plan.

Figures 25a & b show the access of hillside houses to the motorways and the highest and lowest elevation points of built houses on hillside areas. Generally, Kabul city has an elevation of 1791 meters above sea level, but district 1 is located at the center of the city and has the lowest elevation compared to the other parts of the city. The contour lines are added to the 3D model to represent the elevation points of hillside areas. From the interpretation of figures 25a & b, the elevation of hills in study areas various from 1760 to 2170 meters above sea level, and hillside houses are built between 1760 to 2010 meters. The hillside houses from an elevation of 1760 till

1842 meters have proper access to the motorways. The houses from 1842 to 2010 meters do not have any access to the motorways. These houses have no access to social and public services due to the absence of accessibility to the roads.

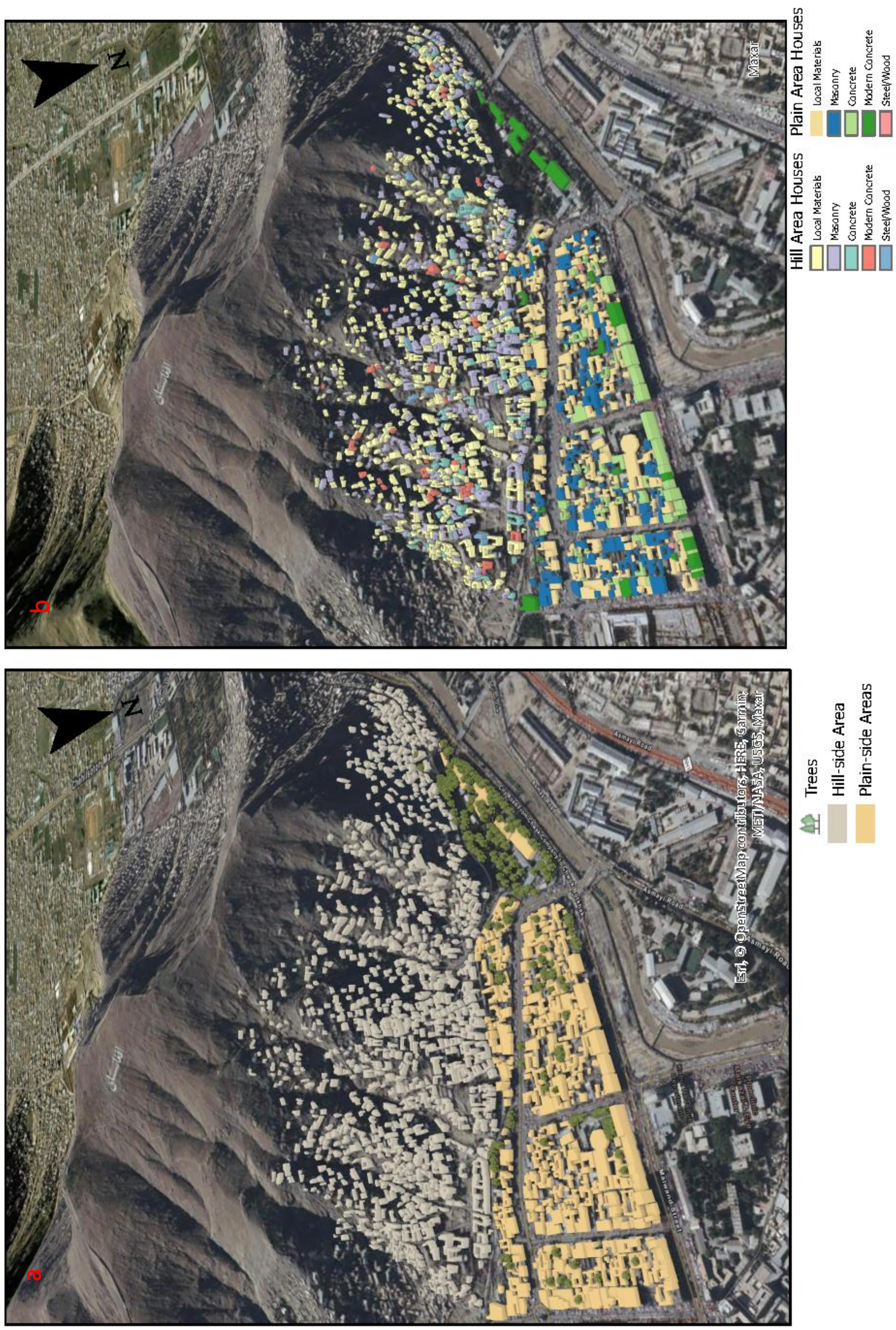


Figure 24: Visual representation of urban space, a) geographic condition of built-up environment, b) built material dynamics of plain and hillside houses.

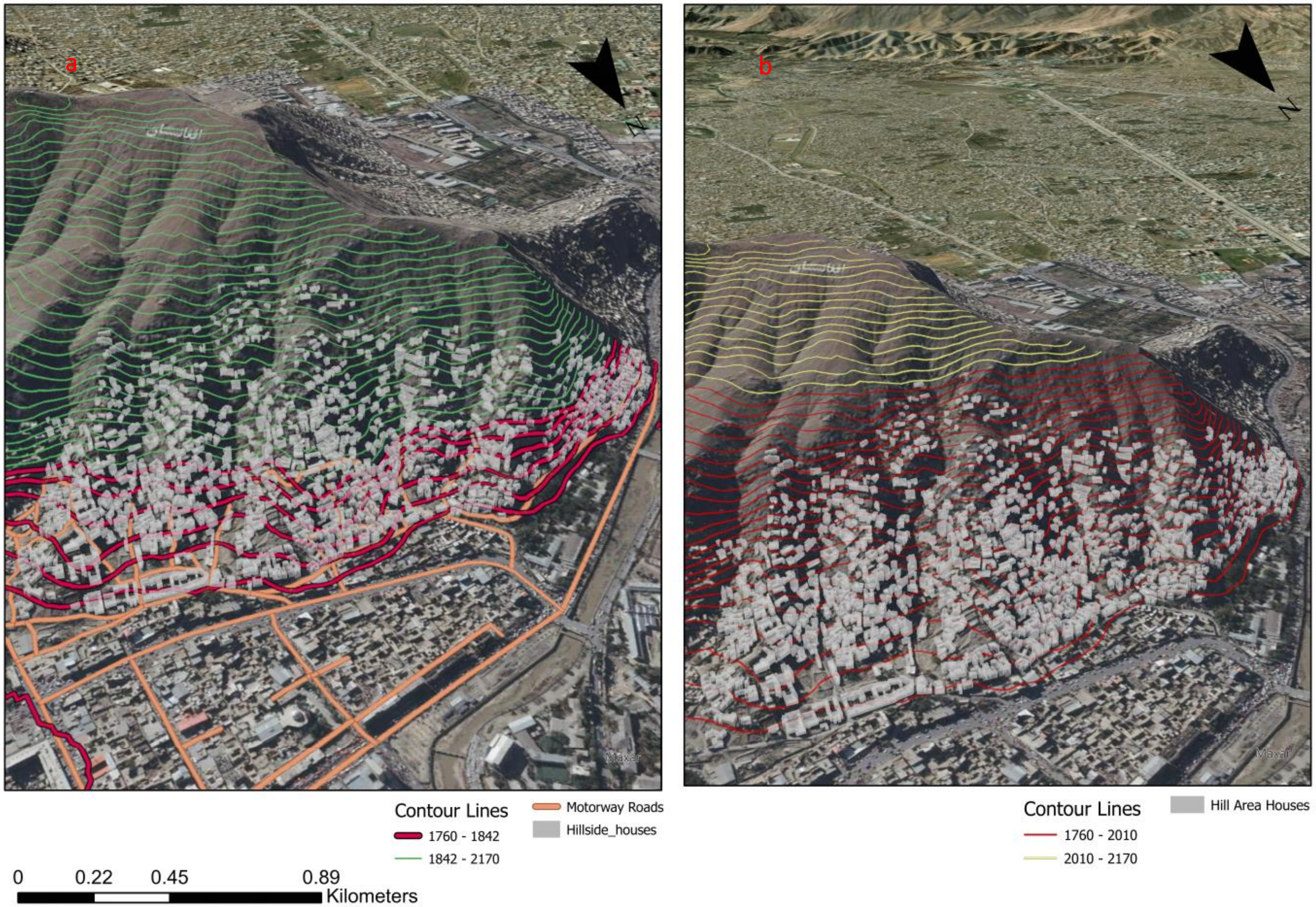


Figure 25: Lack of accessibility to the roads due to elevation variance, a) accessibility to motorways of hillside houses, b) highest and lowest point of elevation of built-up condition.

Figures 26a, b, c, d, e, and f show the street patterns and building features in foot slope and hillside areas. The street patterns in the foot slope areas seem to be more regular and wider than hillside areas. Streets in hillside areas are narrower and irregular. However, both regular and irregular forms of the road network can be found within the area. The model also provides information about the density of houses, which are clustered along the roads, and the distribution of the houses with no access to roads as shown in figure 26d. These houses are built at locations, which are easily accessible by walk. Based on visual interpretation and road network attributes of an open street map, the roads in the foot slope areas are mainly made of asphalt and concrete, while in hillside areas the roads are mixed with sand, gravel, and mud.

Generally, the steep slopes put inhabitants at risk of landslides and harm the city's environment. Due to the current difficulty and cost of extending infrastructure into these more remote regions, most residences are unreachable by car and lack essential services, schools, and community facilities (Figures 26d). Therefore, the Kabul Urban Design Framework (KUDF) considered hilly areas as recreational areas. The development of houses in steep areas has been avoided, particularly areas with a slope steeper than 25 degrees. Therefore, the hillside areas are mostly protected as open spaces network that includes vistas, amenities, and a trail system that connects to neighboring communities. For the housing and substantial development opportunities, the plain areas of the district are considered as mixed-use high-rises. Figures 27a & b show the study area's proposed land use and future development plan, respectively, where many residential, mixed-use and commercial buildings, parks, new road patterns, and recreational areas are considered. Based on the proposed concept plan, the buildings along the Maiwand Roads are preserved, which are built formally. With the plan's implementation, the majority of buildings are going to be affected and demolished, as shown in figure 27c. According to development strategies 4, "Land Administration and Parcel Assembly," the planning and implementation bodies are responsible for compensating affected people due to the integration of plans.

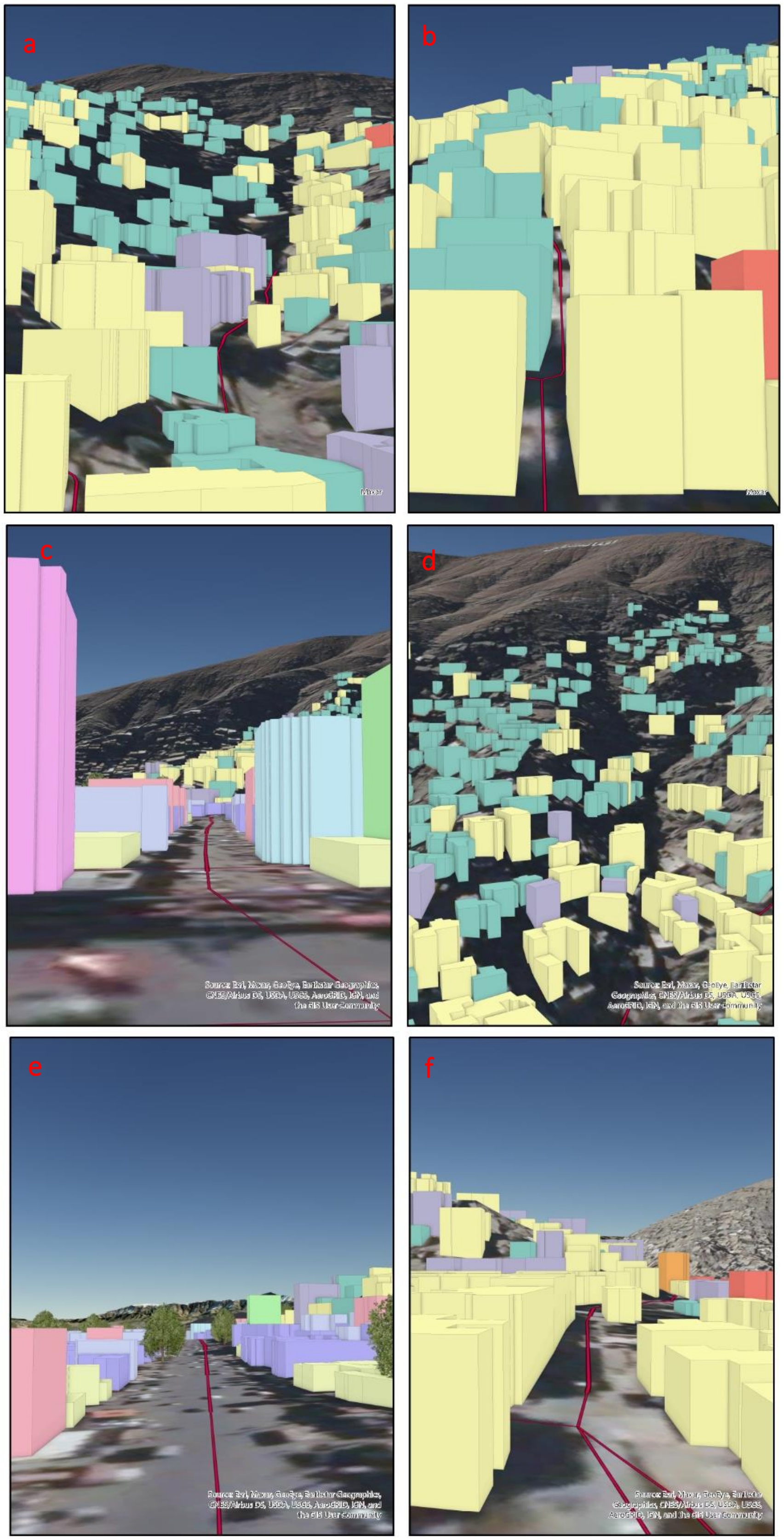


Figure 26: Representation of road patterns in hillside and plain side areas.

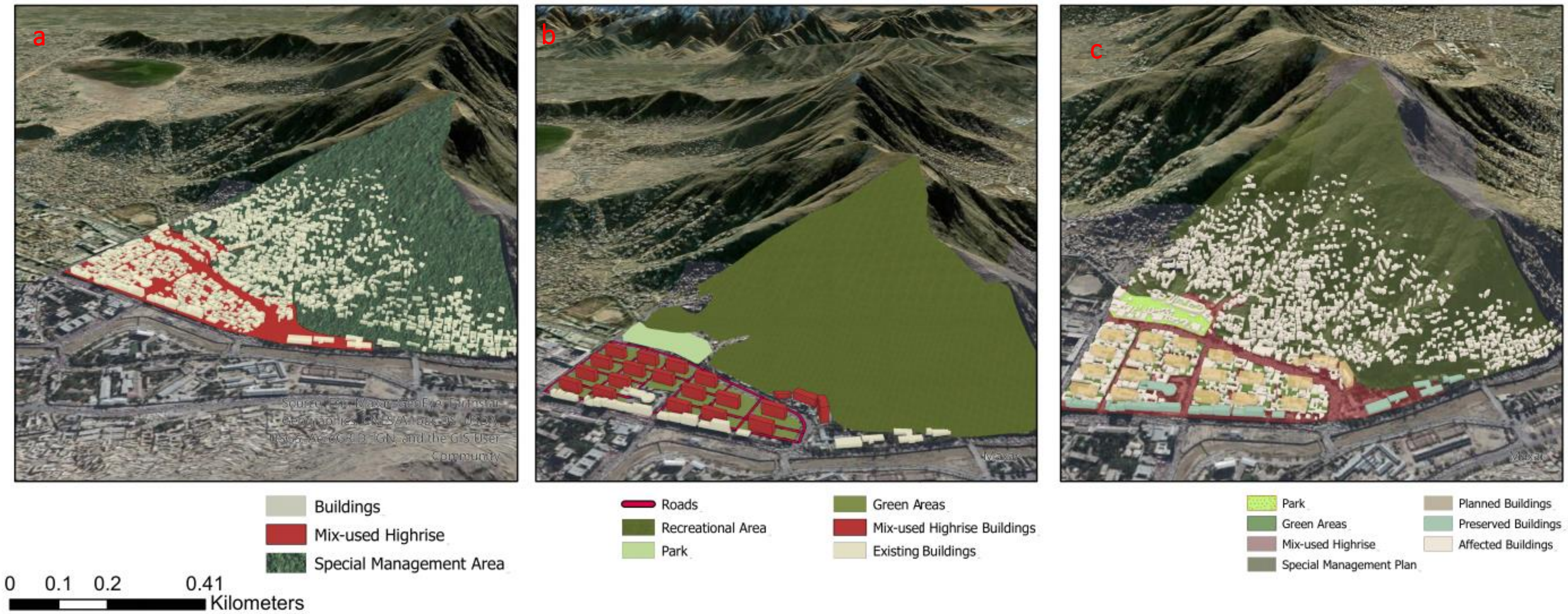


Figure 27: The three -dimensional model for the future development plan of the study area, a) proposed land-use, b) concept plan, and c) change impact 3D models.

4.2.3. Buildings vulnerability to the seismic occurrence

Figure 28 clearly shows that, based on the current vulnerability model used, the two locations react differently to the same sort of seismic occurrence. The hillside areas are more vulnerable than foot slope areas. This is due to the implication effects of their topographic location, and with high value of the building vulnerability index of their built materials. The houses on steep slopes are also vulnerable to landslides, the landslides that may be caused by seismic or other natural hazards. the results show the most vulnerable houses are located in steep slope areas, where the total collapse (damage degree 5) houses built in slopes from 40 to 53 degrees, and surrounding houses are experiencing vulnerability with degree 4. The degree 1 houses that have the lowest vulnerability are clustered in foot slope areas with slopes from 0 to 10 degrees, while houses with degree 3 are located in areas with a slope of 20 to 30 degrees.

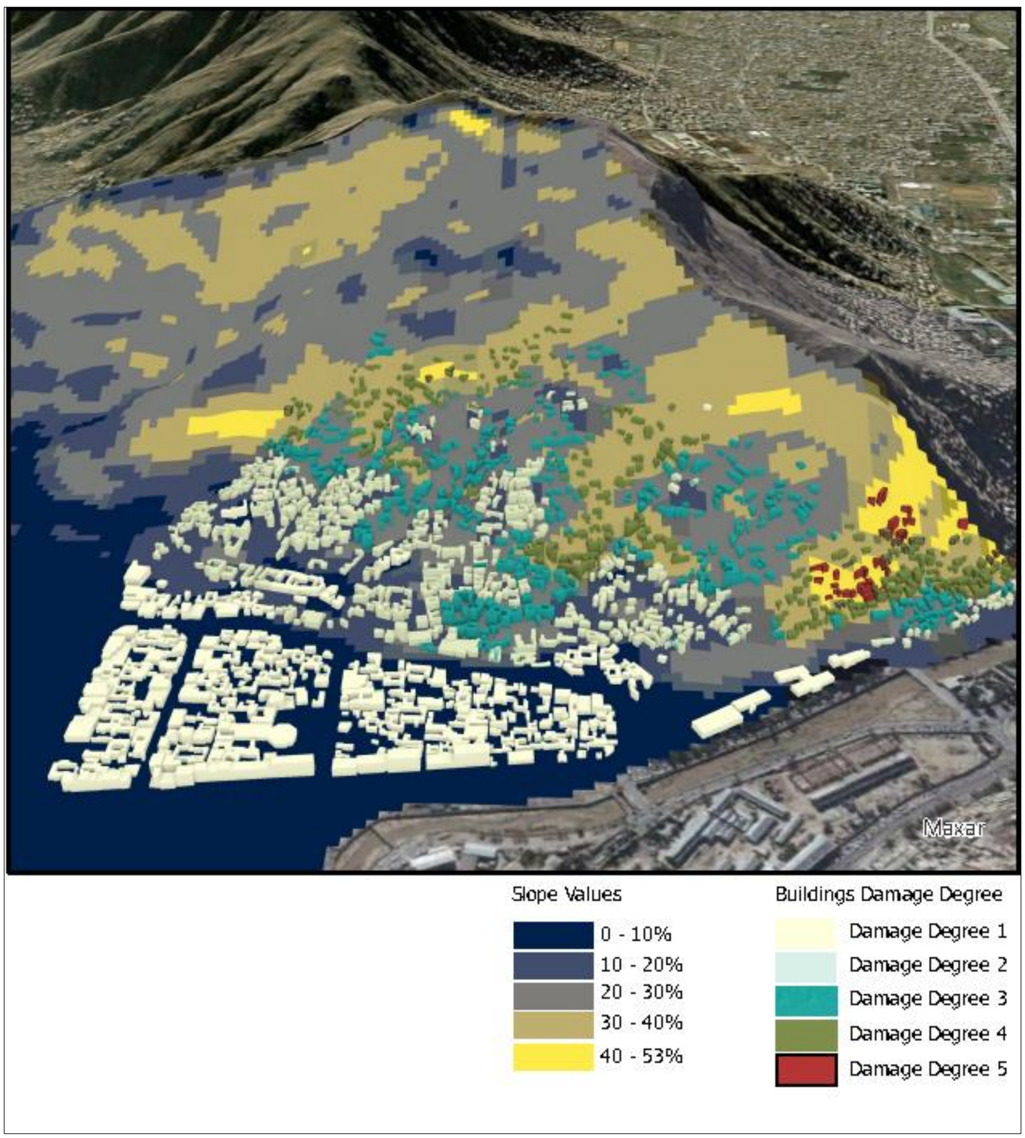


Figure 28: Three-dimensional seismic vulnerability model of study area.

4.3. Sub-objective 3. The assessment of the future practical application of the model by interviewing urban planning experts and practitioners.

This section is about interview results regarding the 3D data framework. The interview was conducted with group one, the urban planning department of Kabul Municipality, which is practicing urban planning projects at the city level. Group two is the group's expert, which includes the freelance urban planning practitioners involved in town planning, and group three, international technical advisors for Kabul urban planning projects. The interviewees were questioned in three main categories; their professional experiences regarding vertical morphologies of informal settlement (section 4.3.1), second the evaluation of the 3D data method (section 4.3.2), and data integration (section 4.2.3).

4.3.1. Professional experience regarding vertical morphologies of informal settlement

All groups were asked about their professional experience regarding the research and the use of terminology the vertical morphologies of the informal settlements in their professional vocabulary. Sector one and two had professional experience with similar researches, but those researches focused on the morphologies and typologies of informal settlements in horizontal levels, not in a vertical level. Sector 3 affirmed their knowledge about the research in their professional and personal experiences, and they are using such kind of researches in their practices.

Regarding the vertical morphologies, sector one deals with the term vertical growth of informal settlements in their daily work. However, there is no academic and formal definition of these vertical morphologies in their professional vocabulary and local policy documents. Sector two acknowledged the existence of multi-story informal settlements, but a formally framed definition of vertical morphologies in their professional vocabulary does not exist. Sector three uses the term vertical morphologies of informal settlements but in the limited era of their practices. As their practices are limited to specific geographic regions, the use of this is minimal.

4.3.2. Evaluation of 3D data framework

All groups were asked about the use of 3D modeling, and to evaluate the consistency and plausibility. All groups mentioned that they use 3D modeling in their daily practices, but it is limited to urban design. They never practice the 3D modeling for the visual representation of informal settlements, and also none of these groups used the EO techniques for urban planning analysis. They also mentioned that the provided 3D models are plausible but are not used in their respective departments. The 3D models attracted all three sectors' attention. They explicated that these models reflect essential information about vertical types of informal settlements; yet, within their departments, there are no comparable data sources that include such quality information. In general, they noted that their 3D models have more detail than their current planning practices of informal settlements.

In a nutshell, all groups instantly grasped both the general idea and its 3D modeling integration. The idea piqued the planners' imagination, and they saw it as a valuable tool for planning and integrating informal settlements. Furthermore, they unequivocally asserted that an urban vertical morphological classification is practically relevant, such as time-series studies. The ability to visualize informal settlements in 3D, in particular, serves the diverse demands of planners in various settings.

4.3.3. Data integration

In a general context, all three sectors found the importance of the 3D data method in the planning and integration of informal settlements. The use of several data sets and integrating them into a single 3D virtual model. All participants in the interview suggested the improvement in the level of details and method for the extraction of building footprints because for covering larger areas for planning purposes, the manual extraction of footprints consumes a lot of time. For the extraction of building footprints, the (semi) automatic methods and the need for suitable data and processing were explained to interviewees. In terms of access to suitable data, groups 1 and 3 suggested that they can have official access to data from national and international sources, but in technical aspects, currently, we lack the capacity, wherein sharing gain knowledge regarding the integration of EO techniques and the 3D data method is required. For increasing the level details, all groups suggested adding required attributes and improving the 3D visual representation. The required attribute information can be requested from existing MIS data from UN-Habitat and integrating into the 3D data method. A high level of detail can help our planners in their planning and decisions making.

.

5. Discussion

This study investigated the types of urban vertical morphologies of informal settlements in Kabul using GIS-based methods with EO techniques and applying a 3D data method and for the visual representation of these morphologies to bridge knowledge gaps. Heiden et al., (2012); Puissant, Zhang, & Skupinski, (2012) stated that the various nomenclature employed in literature does not always correspond to the vocabulary of the intended target audience. As a result, the term urban morphologies are being used in a variety of ways. Since the combination of certain scale levels makes it more difficult to assign and apply the urban morphologies terminology in urban planning. They lead to a wide range of interpretations and implementations of the issue within different research, followed by modifications to regional and local aspects, restricting transferability to other areas or even standardization of urban morphologies' description. Since the term structure is used as the central concept for urban morphological studies in metropolitan areas, the urban structures, and land use may not always be consistent, the study stressed the difference between the two concepts. On top of that, the phrase "urban structure type" refers to the surface's constructional features, not the surface's (useful) function. The overall exterior appearance of buildings or other urban artifacts only indicates their actual function and cannot incorporate land use in a basic urban structure typology.

The typology is mainly combined with a method of implementation that enables the multiscale mapping through different object-based determinations. When it comes to informal mapping settlements, specifically in highly dense and compact informal areas, many authors elucidated (semi) automatic approaches (pixel-based). It wasn't the last time that the authors (see, Gevaert et al., (2017) and Ranguelova et al., (2019)), highlighting the limitations in (semi) automatic mapping of informal settlements. The during the mapping of informal settlements, the size, shape, relative/absolute position, boundary constraints, and topological connections may all be employed within the classification process when categorizing entire objects rather than image pixels. Therefore, the manual classification process is applied for dens and compact informal areas such as in Kabul. But still, there are certain limitations during manual classification, such as time, the need for high-resolution images to detect the objects, and human efforts to keep results with high accuracy. But many authors such as Duque, Patino, & Betancourt, (2017) and Liberati et al., (2018), stressed the capacity of deep learning for automatic extraction of building footprints, and insist on the use of deep learning with high accuracy results.

This study also tried to suggest and define parameters to delineate and identify the classes of urban vertical morphologies of informal settlements. The building height and density are two physical parameters that are selected for classification. Different studies from Fullilove (2018) or Heiden et al. (2012) also used these parameters for classification. Many classification approaches (manual and (semi) automatic) have been researched for urban vertical morphologies. Most remote sensing approaches for classification, like the OBIA approach, required a lot of time and image processing. Due to heterogeneous spatial information in hand, finding a suitable classification approach was a challenging task. Based on available data, a systematic approach, the raster-based Local Climate Zones (LCZs) classification approach, is applied for urban vertical morphologies of informal settlements. Ren et al. (2019) used a similar approach of classifying urban vertical morphologies at the district level. However, in our analysis, the land plots are used as building surface area, but still, the results show significant similarities with Ren et al., (2019) 's classification results. The classification approach can be applied to any other part of Kabul city, but this is questionable that these results can be accountable for other world cities.

In conclusion, this research presented an approach for LCZ classification in Kabul. It has demonstrated how to convert various planning data into systematic urban morphology analysis maps and categorize land surface features using the urban morphology analysis maps. This approach can also be used in other cities that have appropriate planning data.

The LCZ classification map is visualized in two-dimension (2D), classifying the two main types of land surface features such as buildings and land cover. The buildings are classified based on their height and density, from which the types of vertical morphologies of informal settlements are identified. This study also investigated the importance of 3D modeling in the visualization of these typologies and how 3D modeling can be enhanced and applied to represent such dens and complex spatial information. As a result, a 3D data method was proposed. For sustainable implementation, such a framework, comprehensive modeling, and integration techniques are necessary. Still, the 3D city modeling knowledge is relatively scarce among administrations and planners. Thus, a close working relationship and exchange of information between the administrative and technical levels are therefore required for the framework integration. For the integration of the 3D data method, multiple data sets are needed. In our case, different spatial (geo-coded) and non-spatial data (none geo-coded) data were used. 3D visualization of the types of vertical morphologies requires the real shape and size of the buildings. Therefore, manual delineation of building footprints is applied. The limitation that the manual delineation of building footprints has is time-consuming. For this reason, the typologies are visualized at the block level.

Understanding the vertical types of informal morphologies allows us to understand the spatial patterns of informality at various scales. While informal vertical morphologies may look arbitrary and chaotic, there is frequently a rationale for their emergence and growth. The vertical morphologies in informal areas study area are found to be varied in size and shape. The types of vertical morphologies are found with a high concentration of informal buildings. The growth is in an informalized housing complex with informal elements, linear morphologies, and urban infrastructure, such roads are among the types of vertical urban informality identified with different physical characteristics. However, it should be noted that many of the informal vertical morphologies that have been examined contain more than one kind. According to the spatial study of informal vertical morphologies, the district's urban terrain vague is filled by diverse types of urban informality (foot slope and hillside).

The patterns of vertical informal settlements have been analyzed by integrating the 3D data framework. These visual interpretation analyses of height changes in the informal areas reveal a stable and unique geographic feature that can be efficiently studied using 3D modeling. The framework indeed provides for a comprehensive description of vertical urban morphology. However, it is still limited in delivering results on a city scale, especially in the absence of detailed information on building footprints. For further exploration and representation of more spatial information through the framework, some other analytical aspects have been added to the 3D model. These aspects provide 3D information and visualization of the built-up environment regarding buildings' topographic locations and street patterns and physical characteristics of buildings, urban planning, and a 3D vulnerability model. These analyses provide information regarding informal settlements' vertical patterns and physical characteristics to related the departments for their planning and decision-making, and also external users such as architects and engineers. To allow for the collaborative usage of the basic 3D city model for planning purposes.

There is a big conflict between the KUDF proposed land use and the existing condition of the study area. From the visual interpretation of the concept plan, hillside areas are considered recreational areas, which means no housing developments are permitted. By implementation of the concept plan and proposed land use, all hillside houses need to be demolished. In such a case, the implementation body is responsible to pay the compensation and provide new housing opportunities for the affected people, which are challenging tasks for cities such as Kabul in terms of high budget requirements and planning efforts.

However, most technical issues can be recognized and resolved, but organizational and human elements remain critical aspects for Kabul. The adaptation of the 3D data method necessitates the administrative processes, workflows, and training of employees. In conclusion, the 3D data method is the evidence to support our argument that 3D city models are an innovative way to integrate diverse spatial information of urban vertical morphologies. Beyond the case study example, the 3D data method for analyzing the vertical morphological features of informal settlements in different locations throughout the world is currently lacking, which we recommend as a future study path. In conclusion, this study intends to pave the way for identifying the types and patterns of vertical morphologies in Kabul and generating 3D information that significantly accelerates research into improved large-scale assessments of vertical urban morphological features and volumetric characteristics of informal settlements.

6. Conclusion

The research investigated the types of vertical morphologies of informal settlements using the LCZ classification technique and a 3D data method for the three-dimensional representation of these types. The EO techniques have been key tools for investigating the types of informal vertical morphologies at the district scale and using 3D modeling unraveling the vertical patterns of the typologies of informal settlements at the block scale. The main findings of the study are as follows: 1) the types and patterns of vertical morphologies, their physical difference and locational factors in a part of Kabul, where four different types of vertical morphologies are identified (low weight low-rise, compact low-rise, compact mid-rise and open high rise, 2) the 3D data method was investigated and implemented for the visual representation of the vertical morphologies and transformation of the spatial information into 3D geo-visualization through a novel and simple method to effectively assist information sharing and decision-making, 3) assessing the future practical application of the model by interviewing urban planning experts and practitioners.

References

Acero, J. A., Arrizabalaga, J., Kupski, S., & Katzschner, L. (2013). Urban heat island in a coastal urban area in northern Spain. Theoretical and Applied Climatology, 113(1–2), 137–154. https://doi.org/10.1007/s00704-012-0774-z

Afghanistan Population (2020) - Worldometer. (2020). Retrieved July 14, 2020, from https://www.worldometers.info/world-population/afghanistan-population/

Alam, N., Coors, V., & Zlatanova, S. (2013). Detecting shadow for direct radiation using CityGML models for photovoltaic potentiality analysis. Urban and Regional Data Management, UDMS Annual 2013 - Proceedings of the Urban Data Management Society Symposium 2013, 191–196. https://doi.org/10.1201/b14914-23

Aliase Hassany, Naysan Adlparvar, Paul Fishstein, N., & Grubeck, S. S. (2009). The cost of war Afghan 1978-2009. The Cost of War. Retrieved from https://www.oxfam.org/sites/www.oxfam.org/files/afghanistan-the-cost-of-war.pdf

Amirebrahimi, S., Rajabifard, A., Mendis, P., & Ngo, T. (2016). A Planning Decision Support Tool for Assessment and 3D Visualisation of Flood Risk to Buildings. 56th Floodplain Management Association Conference, 8596(December), 1–15. Retrieved from http://dx.doi.org/10.1080/14498596.2016.1189365

Amiri, B. A., & Lukumwena, N. (2018). An Overview of Informal Settlement Upgrading Strategies in Kabul City and the Need for an Integrated Multi-Sector Upgrading Model. Current Urban Studies, 06(03), 348–365. https://doi.org/10.4236/cus.2018.63019

APPRO. (2012). Migration and Urban Development in Kabul: Classification or Accommodation? (October), 30. Retrieved from http://appro.org.af/preview/migration-and-urban-development-in-kabul/

B, C. B., Clarke, C., Clarke, F., Sears, L., & Indian, Y. (2017). Note: Values may be rounded for display. The area of use values is in decimal degrees based upon WGS 1984. Table of Contents.

Barros, J. (2009). City of Slums: self-organization across scales. Change, (January 2002), 1–6.

Batty, M., Axhausen, K., & Fosca, G. (2008). UCL Centre for Advanced Spatial Analysis Papers: Cities as complex systems: scaling, interactions networks, dynamics, and urban morphologies. Analysis, 44(0), 0–18. Retrieved from http://www.springerlink.com/index/j3863x4mm7gu8645.pdf

Biljecki, F., Zhao, J., Stoter, J., & Ledoux, H. (2013). Revisiting the concept of level of detail in 3D city modeling. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2(2W1), 63–74. https://doi.org/10.5194/isprsannals-II-2-W1-63-2013

Bouzarovski, S., Salukvadze, J., & Gentile, M. (2011). A socially resilient urban transition? The contested landscapes of apartment building extensions in two post-communist cities. Urban Studies, 48(13), 2689–2714. https://doi.org/10.1177/0042098010385158

Caracelli, V., & Greene, J. C. (1997). Crafting Mixed-Method Evaluation Designs. (74).

CIA. (2021). The World Factbook. Retrieved from https://www.cia.gov/the-world-factbook/field/total-fertility-rate/country-comparison

CIAA, S. H. S. I. (2012). Sustaining the Working Poor in Kabul Informal Settlements. Kabul. Afghanistan.

Collier, P., Glaeser, E., Venables, T., Blake, M., & Manwaring, P. (2019). Policy options for Kabul's informal settlements. (January 2018). Retrieved from https://www.theigc.org/wp-content/uploads/2018/01/Policy-options-for-Kabuls-informal-settlements-19.01.188.pdf

Collins, J., & Dronova, I. (2019). Urban Landscape Change Analysis Using Local Climate Zones and Object-Based Classification in the Salt Lake Metro Region, Utah, USA. Remote Sensing, 11(13), 1615. https://doi.org/10.3390/rs11131615

Debnath, R., Bardhan, R., & Sunikka-Blank, M. (2019). Discomfort and distress in slum rehabilitation: Investigating a rebound phenomenon using a backcasting approach. Habitat International, 87(February), 75–90. https://doi.org/10.1016/j.habitatint.2019.03.010

Devica, S. (2015). COMMUNITY MAPPING IN INFORMAL SETTLEMENTS FOR BETTER HOUSING AND SERVICE DELIVERY, CAPE TOWN, SOUTH AFRICA. 7(9), 27–44.

Dickmann, F., & Dunker, S. (2014). Visualisierung von 3D-gebäudemodellen – Welche ansprüche stellt die planung an dreidimensionale stadtansichten? Kartographische Nachrichten, 2014(1), 10–16.

Dovey, K., van Oostrum, M., Chatterjee, I., & Shafique, T. (2020). Towards morphogenesis of informal settlements. Habitat International, 104, 102240. https://doi.org/10.1016/j.habitatint.2020.102240

Dovey, K., van Oostrum, M., Chatterjee, I., & Shafique, T. (2020). Towards morphogenesis of informal settlements. Habitat International, 104, 102240. https://doi.org/10.1016/j.habitatint.2020.102240

Dr. Yohannes Gebremedhin. (2005). Preliminary Assessment of Informal Settlements in Kabul City Dr . Yohannes Gebremedhin Land Titling Team Leader & Legal Advisor USAID / LTERA Project Kabul.

Duque, J. C., Patino, J. E., & Betancourt, A. (2017). Exploring the potential of machine learning for automatic slum identification from VHR imagery. Remote Sensing, 9(9), 1–23. https://doi.org/10.3390/rs9090895

Emmanuel, R., & Krüger, E. (2012). Urban heat island and its impact on climate change resilience in a shrinking city: The case of Glasgow, UK. Building and Environment, 53, 137–149. https://doi.org/10.1016/j.buildenv.2012.01.020

Eran Feitelson. (2005). ADVANCING SUSTAINABILITY AT THE SUB-NATIONAL LEVEL. https://doi.org/https://doi.org/10.4324/9781315263304

Fekade, W. (2014). Deficits of formal urban land management and informal responses under rapid urban growth, an international perspective. Habitat International, 24(2), 127–150. https://doi.org/10.1016/S0197-3975(99)00034-X

Firmbach, L., Höfer, R., Thiel, M., Lorz, C., & Weiss, H. (2012). Analyse der Relevanz der aus Fernerkundungsdaten abgeleiteten urbanen Struktureinheiten für ein integriertes Wasserressourcenmanagement. Angewandte Geoinformatik 2012: AGIT 2012 – Symposium Und Fachmesse Angewandte Geoinformatik, 46–51.

Fullilove, M. T. (2018). Element 1: Urban structure. In Urban Alchemy. https://doi.org/10.2307/j.ctt21pxmsz.8

Gauthier, P., & Gilliland, J. (2006). Mapping urban morphology: A classification scheme for interpreting contributions to the study of urban form. Urban Morphology, 10(1), 41–50.

Gevaert, C. M., Persello, C., Sliuzas, R., & Vosselman, G. (2017). Informal settlement classification using point-cloud and image-based features from UAV data. ISPRS Journal of Photogrammetry and Remote Sensing, 125, 225–236. https://doi.org/10.1016/j.isprsjprs.2017.01.017

Glass, K. R., Morkel, C., & Bangay, S. D. (2006). Duplicating road patterns in South African informal settlements using procedural techniques. ACM International Conference on Computer Graphics, Virtual Reality, and Visualisation in Africa, 2006(January), 161–169. https://doi.org/10.1145/1108590.1108616

Golding, J. F., Ashton, C. H., Marsh, V. R., & Thompson, J. W. (1986). Early and late SEPs-The later the potential the greater the relevance to personality. Personality and Individual Differences, 7(6), 787–794. https://doi.org/10.1016/0191-8869(86)90077-2

Hecht, R., Herold, H., Meinel, G., & Buchroithner, M. (2013). Automatic Derivation of Urban Structure Types from Topographic Maps utilizing Image Analysis and Machine Learning. 26th International Cartographic Conference - Proceedings: International Cartographic Association, 2013, (January), 18.

Heiden, U., Heldens, W., Roessner, S., Segl, K., Esch, T., & Mueller, A. (2012). Urban structure type characterization using hyperspectral remote sensing and height information. Landscape and Urban Planning, 105(4), 361–375. https://doi.org/10.1016/j.landurbplan.2012.01.001

Hofmann, P. (2014). Defining robustness measures for OBIA framework: A case study for detecting informal settlements. Global Urban Monitoring and Assessment: Through Earth Observation, (June), 303–324. https://doi.org/10.1201/b17012-21

Holtier, S., Steadman, J. P., & Smith, M. G. (2000). Three-dimensional representation of urban built form in a GIS. Environment and Planning B: Planning and Design, 27(1), 51–72. https://doi.org/10.1068/bst5

Houet, T., & Pigeon, G. (2011). Mapping urban climate zones and quantifying climate behaviors - An application on Toulouse urban area (France). Environmental Pollution, 159(8–9), 2180–2192. https://doi.org/10.1016/j.envpol.2010.12.027

Hussainzad, E. A., Yusof, M. J. M., & Maruthaveeran, S. (2020). Mapping Kabul's Private Urban Green Spaces Using Geographic Information System-Supervised Classification. Journal of Landscape Ecology, 13(1), 42–60. https://doi.org/10.2478/jlecol-2020-0003

Improvements, W., Fixes, B., & Paging, M. (2010). World Machine 2. 2 User's Manual.

Indicator, S. D. G. (2018). Indicator Category: Tier I [11.3.1]. (March), 1–12.

Jahani, A. S. (2020). Formalization of Informal Settlements: A Study on Kabul Urban Areas. Current Urban Studies, 08(03), 446–455. https://doi.org/10.4236/cus.2020.83025

Jaitman, L. (2013). Evaluation of Slum Upgrading Programs: A Literature Review. SSRN Electronic Journal, (November 2013). Retrieved from https://publications.iadb.org/publications/english/document/Evaluation-of-Slum-Upgrading-Programs-Literature-Review-and-Methodological-Approaches.pdf

Jones, P. (2017). Formalizing the informal: Understanding the position of informal settlements and slums in sustainable urbanization policies and strategies in Bandung, Indonesia. Sustainability (Switzerland), 9(8). https://doi.org/10.3390/su9081436

Joshi, P., Sen, S., & Hobson, J. (2002). Experiences with surveying and mapping Pune and Sangli slums on a geographical information system (GIS). Environment and Urbanization, 14(2), 225–240. https://doi.org/10.1177/095624780201400218

Kabul Municipality. (2015). State of Afghan Cities (2015th ed.). Retrieved from https://unhabitat.org/sites/default/files/download-manager-files/State of Afghan Cities 2015 Volume_1.pdf.

Kamalipour, H. (2020). Improvising places: The fluidity of space in informal settlements. Sustainability (Switzerland), 12(6). https://doi.org/10.3390/su12062293

Keifer, G., & Effenberger, F. (1996). The Compact City: A Sustainable Urban Form. In Angewandte Chemie International Edition (Vol. 6).

Kemper, T., & Pesaresi, M. (2019). Searching for robust & objective EO-based indicators for slum characterization. 1–25.

Koenig, R., & Bauriedel, C. (2009). Generating settlement structures: A method for urban planning and analysis supported by cellular automata. Environment and Planning B: Planning and Design, 36(4), 602–624. https://doi.org/10.1068/b34025

Kohli, D., Sliuzas, R., Kerle, N., & Stein, A. (2012). An ontology of slums for image-based classification. Computers, Environment and Urban Systems, 36(2), 154–163. https://doi.org/10.1016/j.compenvurbsys.2011.11.001

Kyttä, M., Broberg, A., Tzoulas, T., & Snabb, K. (2013). Towards contextually sensitive urban densification: Location-based softGIS knowledge revealing perceived residential environmental quality. Landscape and Urban Planning, 113, 30–46. https://doi.org/10.1016/j.landurbplan.2013.01.008

Leavitt, N. (1999). Online 3D: Still waiting after all these years. Computer, 21(7), 4–7. Retrieved from http://search.proquest.com/docview/197397429?accountid=15533

Lehner, A., & Blaschke, T. (2019). A generic classification scheme for urban structure types. Remote Sensing, 11(2). https://doi.org/10.3390/rs11020173

Leland, C. H., & Harste, J. C. (2005). Doing what we want to become preparing new urban teachers. Urban Education, 40(1), 60–77. https://doi.org/10.1177/0042085904270374

Li, M., Koks, E., Taubenböck, H., & van Vliet, J. (2020). Continental-scale mapping and analysis of 3D building structure. Remote Sensing of Environment, 245(May), 111859. https://doi.org/10.1016/j.rse.2020.111859

Liberati, A., Altman, D., Tetzlaff, J., Mulrow, C., Gotzsche, P., Loannidis, J., … Moher, D. (2018). Enhanced Reader.pdf. Nature, Vol. 388, pp. 539–547.

Maximum, M. M., & Longitude, L. L. (2018). Table 1: Geographic (datum) transformations: well-known IDs, accuracies, and areas of use. 1–130.

Meinel, G., Hecht, R., Herold, H., Schiller, G., Spangenberg, M., Burgdorf, M., & Kawka, R. (2008). Automatische Ableitung von stadtstrukturellen Grundlagendaten und Integration in einem Geographischen Informationssystem. Retrieved from http://d-nb.info/990137678/34

Mills G., Ching, J., See, L., Bechtel, B., Feddema, J., Masson, V., ... & Steeneveld, G. J. (2015). An Introduction to the WUDAPT project. Proceedings of the ICUC9. Meteo France, (February 2016), 6.

Minnery, J., Argo, T., Winarso, H., Hau, D., Veneracion, C. C., Forbes, D., & Childs, I. (2013). Slum upgrading and urban governance: Case studies in three southeast Asian cities. Habitat International, 39, 162–169. https://doi.org/10.1016/j.habitatint.2012.12.002

Morton, P. J., Horne, M., Dalton, R. C., & Thompson, E. M. (2012). Virtual City Models: Avoidance of Obsolescence. Education and Research in Computer Aided Architectural Design in Europe-ECAADe, 1(June 2015), 213–224.

Moudon, A. V. (1997). Urban morphology as an emerging interdisciplinary field. Urban Morphology. New Phytologist, 55(1), 3–10. https://doi.org/10.1111/j.1469-8137.1956.tb05265.x

Nazire, H., Kita, M., Okyere, S. A., & Matsubara, S. (2016). Effects of Informal Settlement Upgrading in Kabul City, Afghanistan: A Case Study of Afshar Area. Current Urban Studies, 04(04), 476–494. https://doi.org/10.4236/cus.2016.44031

Niva, V., Taka, M., & Varis, O. (2019). Rural-Urban Migration and the Growth of Informal Settlements: A Socio-Ecological System Conceptualization with Insights Through a "Water Lens." Sustainability, 11(12), 3487. https://doi.org/10.3390/su11123487

Omar, O., El-Messeidy, R., & Youssef, M. (2016). Impact of 3D Simulation Modeling on Architectural Design Education. (March). https://doi.org/10.13140/RG.2.1.4053.1608

Pan, Z., Xu, J., Guo, Y., Hu, Y., & Wang, G. (2020). Deep learning segmentation and classification for urban villages using a worldview satellite image based on U-net. Remote Sensing, 12(10), 1–17. https://doi.org/10.3390/rs12101574

Parish, Y. I. H., & Müller, P. (2001). Procedural modeling of cities. Proceedings of the 28th Annual Conference on Computer Graphics and Interactive Techniques, SIGGRAPH 2001, (August), 301–308. https://doi.org/10.1145/383259.383292

Peter, van O., Friso, P., Sisi, Z., & Elfriede, M. F. (2008). Lecture notes in geoinformation and cartography. In Advances in 3D Geoinformation Systems. Retrieved from https://link-springer-com.kuleuven.ezproxy.kuleuven.be/content/pdf/10.1007%2F978-3-540-36731-4.pdf

Puissant, a., Zhang, W., & Skupinski, G. (2012). Urban morphology analysis by high and very high spatial resolution remote sensing. 4th GEOBIA, 524–529.

Ranguelova, E., Weel, B., Roy, D., Kuffer, M., Pfeffer, K., & Lees, M. (2019). Image-based classification of slums, built-up and non-built-up areas in Kalyan and Bangalore, India. European Journal of Remote Sensing, 52(sup1), 40–61. https://doi.org/10.1080/22797254.2018.1535838

Rashed, T., & Weeks, J. (2003). Assessing vulnerability to earthquake hazards through spatial multicriteria analysis of urban areas. In International Journal of Geographical Information Science (Vol. 17). https://doi.org/10.1080/1365881031000114071

Ren, C., Cai, M., Li, X., Zhang, L., Wang, R., Xu, Y., & Ng, E. (2019). Assessment of Local Climate Zone Classification Maps of Cities in China and Feasible Refinements. Scientific Reports, 9(1), 1–11. https://doi.org/10.1038/s41598-019-55444-9

Ribeiro, S. C. L., Jarzabek-Rychard, M., Cintra, J. P., & Maas, H. G. (2019). DESCRIBING the VERTICAL STRUCTURE of INFORMAL SETTLEMENTS based on LIDAR DATA - A CASE STUDY for FAVELAS (SLUMS) in SAO PAULO CITY. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 4(2/W5), 437–444. https://doi.org/10.5194/isprs-annals-IV-2-W5-437-2019

Rüther, H., Martine, H. M., & Mtalo, E. G. (2002). Application of snakes and dynamic programming optimization technique in modeling of buildings in informal settlement areas. ISPRS Journal of Photogrammetry and Remote Sensing, 56(4), 269–282. https://doi.org/10.1016/S0924-2716(02)00062-X

Sabri, S., Rajabifard, A., Ho, S., Amirebrahimi, S., & Bishop, I. (2016). Leveraging vgi integrated with 3d spatial technology to support urban intensification in Melbourne, Australia. Urban Planning, 1(2), 32–48. https://doi.org/10.17645/up.v1i2.623

Sasaki. (2020). Kabul Urban Design Framework. Retrieved July 7, 2020, from https://www.sasaki.com/projects/kabul-urban-design-framework/

Shahzad, M., & Zhu, X. X. (2015). Detection of buildings in spaceborne TomoSAR point clouds via hybrid region growing and energy minimization technique. 2015 Joint Urban Remote Sensing Event, JURSE 2015, (1), 15–18. https://doi.org/10.1109/JURSE.2015.7120480

Sliuzas, R., Mboup, G., & de Sherbinin, A. (2008). Report of the expert group meeting on slum identification and mapping. Report by CIESIN, UN-Habitat, ITC, 36.

Smelik, R. M., Tutenel, T., Bidarra, R., & Benes, B. (2014). A survey on procedural modeling for virtual worlds. Computer Graphics Forum, 33(6), 31–50. https://doi.org/10.1111/cgf.12276

Sminkey, P. V., & LeDoux, J. (2016). Case Management Ethics. In Professional Case Management (Vol. 21). https://doi.org/10.1097/ncm.0000000000000166

Stasolla, M., & Gamba, P. (2008). Spatial indexes for the extraction of formal and informal human settlements from high-resolution SAR images. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 1(2), 98–106. https://doi.org/10.1109/JSTARS.2008.921099

Steiniger, S.; Lange, T.; Burghardt, D.; Weibel, R. (2008). 2An approach for the classification of urban building structures based on discriminant analysis techniques. 31–59.

Stewart, I. D., & Oke, T. R. (2012). Local climate zones for urban temperature studies. Bulletin of the American Meteorological Society, 93(12), 1879–1900. https://doi.org/10.1175/BAMS-D-11-00019.1

Taubenböck, H., & Kraff, N. J. (2014). The physical face of slums: A structural comparison of slums in Mumbai, India, based on remotely sensed data. Journal of Housing and the Built Environment, 29(1), 15–38. https://doi.org/10.1007/s10901-013-9333-x

Taubenböck, H., Kraff, N. J., & Wurm, M. (2018). The morphology of the Arrival City - A global categorization based on literature surveys and remotely sensed data. Applied Geography, 92(January), 150–167. https://doi.org/10.1016/j.apgeog.2018.02.002

Tunas, D. (2008). the Spatial Economy in the Urban Informal Settlement Devisari Tunas (Katholieke Universiteit Leuven). Retrieved from file:///E:/m.,.,/tunas_20081124.pdf

Turksever, A. S. (2015). 3D Modeling With City Engine. (June 2015). https://doi.org/10.13140/RG.2.2.30548.30085

Turkstra, J. (2010). Peace Building in Afghanistan through Settlement Regularization (ISOCARP, Ed.). Retrieved from http://www.isocarp.net/Data/case_studies/1639.pdf

UNDP, I. E. O. (IEO). (2020). The Islamic Republic of Afghanistan. IMF Staff Country Reports, 20(43). https://doi.org/10.5089/9781513529912.002

United Nations (Habitat III). (2017). New Urban agenda. Retrieved from www.habitat3.org

United Nations. (2019). World Population Prospects 2019. In Department of Economic and Social Affairs. World Population Prospects 2019. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12283219

Verdonck, M. L., Okujeni, A., van der Linden, S., Demuzere, M., De Wulf, R., & Van Coillie, F. (2017). Influence of neighborhood information on 'Local Climate Zone' mapping in heterogeneous cities. International Journal of Applied Earth Observation and Geoinformation, 62(June), 102–113. https://doi.org/10.1016/j.jag.2017.05.017

Walde, I., Hese, S., Berger, C., & Schmullius, C. (2013). Graph-based mapping of urban structure types from high-resolution satellite image objects - A case study of the German cities Rostock and Erfurt. IEEE Geoscience and Remote Sensing Letters, 10(4), 932–936. https://doi.org/10.1109/LGRS.2013.2252323

Walde, I., Hese, S., Berger, C., & Schmullius, C. (2014). From land cover graphs to urban structure types. International Journal of Geographical Information Science, 28(3), 584–609. https://doi.org/10.1080/13658816.2013.865189

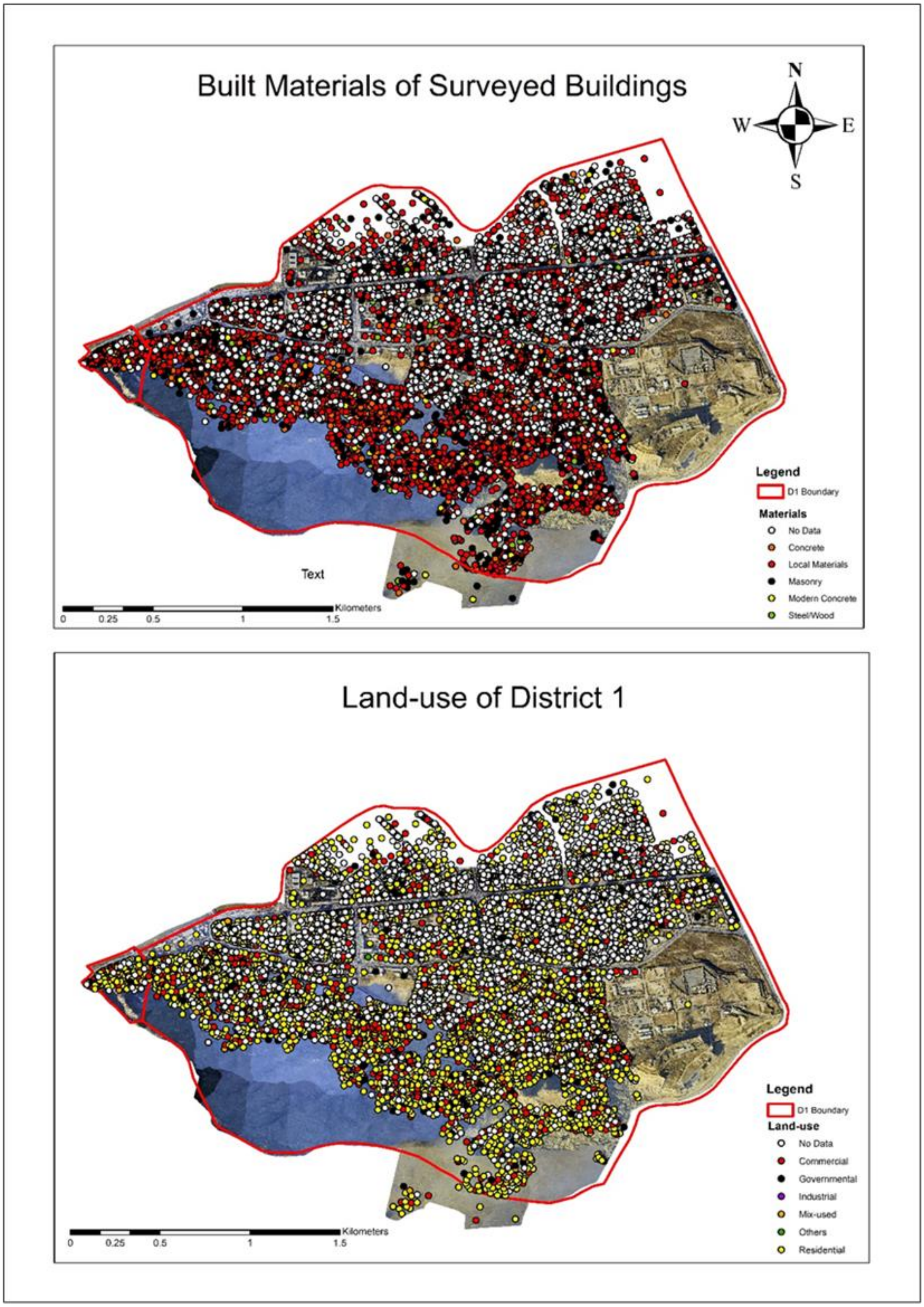
Wergles, N., & Muhar, A. (2009). The role of computer visualization in the communication of urban design-A comparison of viewer responses to visualizations versus on-site visits. Landscape and Urban Planning, 91(4), 171–182. https://doi.org/10.1016/j.landurbplan.2008.12.010

Xu, G., Dong, T., Cobbinah, P. B., Jiao, L., Sumari, N. S., Chai, B., & Liu, Y. (2019). Urban expansion and form change across African cities with a global outlook: Spatiotemporal analysis of urban land densities. Journal of Cleaner Production, 224(July), 802–810. https://doi.org/10.1016/j.jclepro.2019.03.276

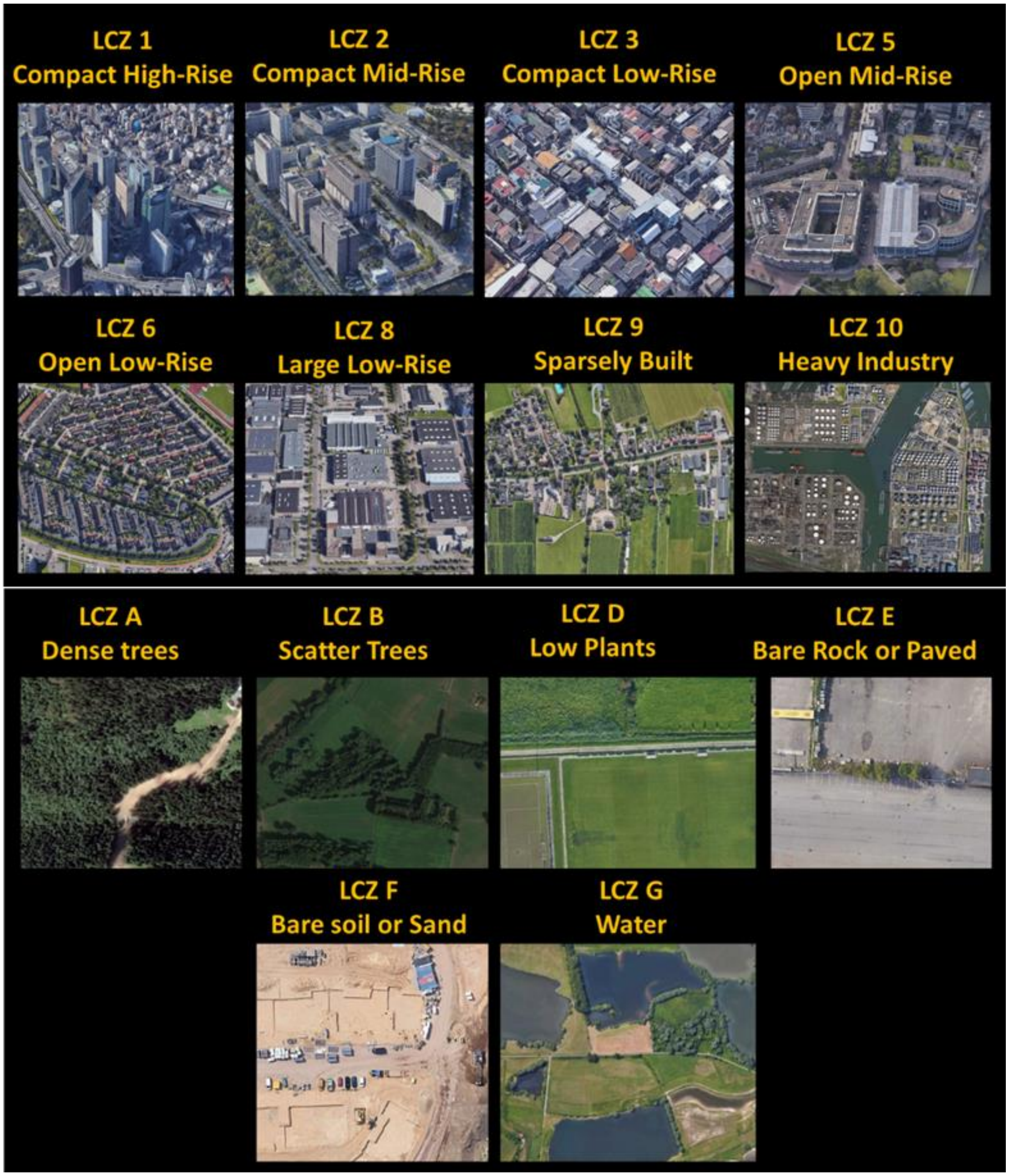
Yin, L. (2017). Street-level urban design qualities for walkability: Combining 2D and 3D GIS measures. Computers, Environment and Urban Systems, 64, 288–296. https://doi.org/10.1016/j.compenvurbsys.2017.04.001

Appendices

Appendix 1. MIS Data Distribution



Appendix 2. Representative LCZ classes (Stewart and Oke, 2012).



Appendix 3. Building information Sheet

Building Information Sheet

Section A: Information on Dwelling Unit

1. Dwelling Type and Physical Characteristic.
(What is the type and physical characteristics of the house?

Property Adress						
Number of Stories						
Property Owner	Governamental	☐	Privete	☐	Governmental & Privete	☐
Property type	Single buidling	☐	Detouch house	☐	Detouch house (apartment type)	☐
Type of Tital Deed	Formal	☐	Customary	☐	Age	☐
Building Material	Local	☐	Masonry	☐	Concrate	☐
Fassade	Concrete with plaster	☐	Bricks & PCC	☐	Local with mate	☐
Shape of the Roof	Flat	☐	Hipped	☐	Salt box	☐
Roof Materials	RCC	☐	Bricks and Girders	☐	Wooden boards and Girders	☐
Legal Permit	Yes		No			
	If Yes!					
Obeyed the Land-use and Zoning rules	Yes	☐	No	☐	If No, How?	
(Plot Boundary)						
	Mate	☐	Brick	☐	Stone	☐

2. Spatial Information

Built-up Area	Formal	☐	Informal	☐		
Current Land Use	Commercial	☐	Residential	☐	Mixed used	☐

3. Infrastructure

(Access Road) Availability of Roads

Is the property has the access to road?	Yes	☐	No	☐	If Yes, is it accessible to cars?	
If yes What Type?	Asphalt	☐	Concrate	☐	Bund	☐
From which Side?	North	☐	South	☐	East	☐

(Access to Utilities)

Water Supply	Yes	☐	No	☐	if Yes
Sewerage	Yes	☐	No	☐	if Yes
Drainage	Yes	☐	No	☐	if Yes
Park	Yes	☐	No	☐	if Yes
Mosque	Yes	☐	No	☐	if Yes
Clinic	Yes	☐	No	☐	if Yes
Others	Yes	☐	No	☐	if Yes

Human Waste Management

Septic wells	Yes	☐	No	☐
Septic Tanks	Yes	☐	No	☐
Waste Absorption Wells	Yes	☐	No	☐
Local Disposable wells	Yes	☐	No	☐

Section B: Energy Sources

What is the main type of energy source used in this dwelling?

Energy Sources	Cooking	Heating	lighting
Electricity	☐	☐	☐
Gas	☐	☐	☐
Paraffin	☐	☐	☐
Coal	☐	☐	☐
Wood	☐	☐	☐
Others	☐	☐	☐

Appendix 4. Interview Questions

My research topic is 3D modeling and analysis of vertical morphologies of informal settlements and I am investigating an integrative 3D data method based on EO techniques for analyzing the types and patterns of vertical informality in Kabul.

Interview Questions

Professional Experience

1. Could you describe your professional/personal experience with this research?
2. Are the used terminology “vertical morphologies of informal settlements” coinciding with your professional vocabulary?

Evaluation of 3D data framework

3. Do you use 3D modeling with EO techniques in your daily practices?
4. According to your professional experience, what could be the usefulness of the information provided by the 3D modeling for supporting urban planning in Kabul?
5. How do you evaluate the 3D modeling in terms of its plausibility?
6. How do you evaluate the model in terms of its consistency?

Integration of Data

As part of the last step of the research, we'd want to hear your thoughts on the model's suitability for the application.

The reason that you have been invited for an interview is that you have been using 3D modeling in the urban planning application, and some of you were even active in studies on the same issue. As a result, I much value your attendance and input during this last stage of my study.

The goal of the research was to investigate the feasibility of combining several data sets and integrating them into a single three-dimensional (3D) virtual model. The UAV image, different raster, and vector data, and Metadata (UN-Habitat survey data) were used as sourced data for completion of the 3D model in the GIS environment (ArcMap, ArcGIS Pro). Due to the massive disparities in coordinate systems, file formats, and other characteristics, the material had to be handled separately before combining the data sets. The aforementioned data sources were not originally not used for 3D modeling purposes, therefore each data was processed and used for a single purpose as a 3D data framework.

The 3d model has been built for the following reasons: the 3D visual representation of informal vertical morphologies, representation of heterogeneous spatial information for urban land management, and buildings vulnerability to the seismic occurrence. For visualization of informal vertical morphologies, the 3D data method is used to visualize the identified vertical morphologies in terms of volume or floor space to examine their outward and upward patterns and influence on their urban form of the study area. For urban land management, the framework is used to focuses on the visual representation of urban space and future urban planning of informal settlements. Where the urban space determines the level of geographical condition elicited by the visual. In practice, urban design is concerned with the physical development of the fundamental components that comprise the built environment, such as buildings, streets, and landscape features. For future urban planning for the study area, one type of conceptual plan (master plan) is examined. The vulnerability analysis of the building, the framework is used to visualize the damage degree and vulnerability levels of the buildings in terms of their built materials, height, and topographic location due to seismic occurrence.

7. In your judgment, which improvements should be added concerning input data, level of details, and the research's integration in urban planning?

8. Is there anything else you'd like to add that hasn't been covered by the questions I've already posed?