ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
COLLEGE OF NATURAL SCEINCES
DEPARTMENT OF COMPUTER SCIENCE

INFORMAL SETTLEMENT AND BUILDING CONSTRUCTION IDENTIFICATION USING CHANGE DETECTION: CASE OF ADDIS ABABA

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DEDICATION

To Jesus Christ and to my father Mekonnen Bekele

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Acronyms

AACA	-	Addis Ababa City Administration
GIS	-	Geographic Information System
GPS	-	Global Positioning System
LABPA	-	Land Administration and Building Permit Authority
LLRAS	-	Land and Land Related Administration Section
LULC	-	Land Use Land Cover
ORAAMP	-	Office for the Revision of the Addis Ababa Master Plan
UNPRB	-	United Nations Population Reference Bureau

ABSTRACT

Population growths together with poverty are obstacles in the development and sustainable life. Lack of formal land provision and the high demand for housing increased the growth of the illegal/informal sector of housing. Getting up to date data of informal settlement from public register and urban cadaster are great challenge. This is because they are dynamic and often changing structures and forms. This is especially the case in developing countries. Informal settlement information is required for management and planning activities of urban region. The purpose of the study is to detect and analyze informal settlements using multi-temporal aerial photographs and cadastral map using change detection. The model employed unsupervised building identification and image differencing change detection in the identification of informal settlements and building construction. First, buildings are identified from the aerial photographs in the initial (1992) and target (2010) reference times separately. Then, the change detection between building maps in the initial and target reference times are used to identify the buildings constructed in the study period (1992-2010). Finally, the change detection between the labeled cadastral map and change detected building map are used to identify the informal settlements and building construction.

The model is implemented using Matlab. The model was tested using sections of woredas 10 and 11 in Yeka sub-city, Addis Ababa. Manually identified informal buildings are used in the evaluation of performance of the system. Overall building identification and informal settlement and building construction identification accuracy were tested by Confusion Matrices. It has been found that tremendous informal settlements occurred over the study period. The results indicated that from the new settlement constructed between the periods 1992 to 2010 28.9% are informal settlements with annual growth rate around 1.61%.

Keywords:

Informal Settlement Identification, Building Identification, Image Differencing Change Detection, Cadastral Map, Multi-temporal Aerial Photograph, Addis Ababa City

CHAPTER ONE

INTRODUCTION

1.1 Background

Population increment and land demand for settlement, commercial and industrial expansion and its impact on the environment have been largely raising issues in many discussions since the last few decades. According to the United Nations Population Reference Bureau (UNPRB) report of 2000, the world has experienced a tremendous urban growth and population increment in the last decades. For the first time in history, more than half of its human population, 3.3 billion people has been living in urban areas in 2000. By 2030, this is expected to grow to almost 5 billion [28]. While the world‟s urban population grew very rapidly (from 220 million to 2.8 billion) over the 20th century, the next few decades will see an unprecedented scale of urban growth in the developing world. This will be particularly notable in Africa and Asia where the urban population will double between 2000 and 2030. By 2030, the towns and cities of the developing world will make up 81% of urban population of the world [28].

People have started to migrate from rural areas to urban, attracted by the opportunities created by a more dynamic economy and by the apparent easier life within the cities. The result of this very rapid and unplanned urban growth shows that 30% to 60% of residents of most large cities in developing countries live in informal settlements [27]. The informal settlements problem, which are not officially recognized in many countries need to be recognized as a problem and solutions must be found under certain circumstances or conditions. Informal settlements are without any doubt a reality and their rapid growth is one of the major challenges for the authorities in charge of providing essential services and managing land tenure.

Addis Ababa was founded in 1886. It grew in an unorganized way. However, today it is characterized by large avenues and well planned areas. Like many other cities of the continent, its population has grown quickly, reaching more than three million due to in-migration and natural increase [20].

In recent times, informal settlements in Addis Ababa are inevitably increasing without official approval [21]. These illegal developments affect the city‟s planned development. Supervision and inspection of the illegal development has become the routine task of local woredas and municipality administrations of the city. The traditional approach for those inspections often requires a large number of inspectors, locally known to be *„afrash gibrehayil"*, which literally means illegal house destruction team.

In 1996, the Addis Ababa city administration implemented a cadastral project to register all property owners so that valuation and taxes could be applied to properties. A multi-purpose cadaster was established and data collected to support urban planning, land and property transfers, the issuing of building permits and title deeds, and compensation payment. Overtime insufficient updating mechanisms led to a significant erosion of the cadastral map reliability. This leads to widespread informal property settlements and inadequately secured land records. To alleviate these problems in 2009 the Addis Ababa city government made a decision to develop and implement a new integrated land information system based on information communications technology (ICT). The primary purpose of the system was to establish real property registration and land cadaster system able to support land registration process and municipal functions [36].

The trend in urban growth has been quite difficult to manage and regulate. To monitor the extent of this problem, basically the stake holders should know where informal settlements and how many exist and how many people will need basic services. Answers to some of these questions can now be found using new methodologies, derived from technologies, developed to study from aerial photographs or satellite imagery in combination with local competences and more accessible software and hardware.

Aerial or remote sensing imagery now has the capacity to provide planners and decision-makers with information previously restricted to specialized units, at competitive costs, which is opening new ways to monitor the dynamics of fast growing settlements. In Addis Ababa there are no extensive studies conducted related to informal settlements and their impacts using remotely sensed imagery and city cadastral map. Hence, urban planners and decision makers should consider the potential of remote sensing, image processing, change detection and GIS tools to detect, monitor and evaluate the informal settlements in the city in particular and in the country in general. In this work, remote sensing images and cadastral map are applied to detect automatically and analyze the informal settlements and construction in sections of Addis Ababa.

1.2 Statement of the Problem

According to the United Nations Habitat report in 2013 most of the population growth in the next 15 years from 2013 to 2028 will be urban growth, and the vast majority of it will take place in the developing countries [30]. The population growth rate for the years 2000-2020 is estimated at 1.3 percent in developing regions and 2.4 percent in Sub-Saharan Africa compared to only 0.1 percent in developed regions. Countries in Africa, in the year 2000 only 37.1 percent of their total populations were urban, this is estimated to grow up to 47.8 percent by the year 2020 [26]. Therefore, population growths together with poverty are obstacles in the development and sustainable life.

In Addis Ababa the housing need and the shortage is one of the worst problems that is facing the city administration. The Addis Ababa housing development project office recognized that the lack of formal land provision and the high demand for housing increased the growth of the illegal/informal sector of housing [20].

Getting up to date data of informal settlement from public register and urban cadaster has a great challenge. This is because they are dynamic and often changing structures and forms, which is especially the case in developing countries [3].

Thus, a major focus in sustainable development and issues related to it in Addis Ababa should be directed towards the urban environment and problems caused by rapid urban growth. Given the facts raised above in the urban areas of the developing world, there is an urgent need for fast decision making and planning in order for the government officials and urban planners to maintain at least some control of the city growth and informal settlement. This is not possible without up-to-date information about informal settlement and constructions. The advent of Remote Sensing technologies, existing GIS data and processing techniques can fill this gap. Therefore, the research will answer the following questions:

- How can we identify if there are major informal settlements and building construction in parts of the city of Addis Ababa?
- How can we identify the spatial extent of the informal settlement and where are these?

1.3 Objectives

General Objective

The general objective of this research work is to design and develop a model that can identify settlements, which don"t have legal claim using high resolution aerial photographs and cadastral map in case of Addis Ababa city.

Specific Objectives

The specific objectives of the work are:

- Review of literatures and related work
- Collection of relevant data and documents of informal settlements
- Study and analyze the nature of informal settlements
- Study and analyze the processing of high resolution satellite images and aerial photographs.
- Design an architecture that can identify informal settlements and building construction using high resolution aerial photographs and cadastral map.
- Develop the prototype of the model
- Test the performance of the prototype system.
- Assess the accuracy of the building identification and informal settlement and building construction identification.
- Put forward a recommendation or set of recommendations that may form the basis for a sound solution for decision makers.

1.4 Scope and Limitations of the Study

An image acquired from aerial photograph and remote sensing varies from low to high resolution and also several approaches have been modeled for informal settlement identification from low to high resolution remote sensing images. However, this work identifies informal settlements from high resolution aerial photograph. Even though buildings constructed without legal permission inside legal built up parcels are informal buildings, the work doesn"t identify as informal settlement. The work is limited to identification of buildings which are constructed in sections of the land which are not permitted for settlement and building construction.

1.5 Methodology

To achieve the general objectives of the research, the following methodologies will be used.

1.5.1 Literature Review

Different literatures which are considered to be relevant for the research will be reviewed and some of the concepts will be adopted for our work. Since our research work is on informal settlement identification it touches several numbers of areas: geo-referencing aerial photograph, image processing of aerial map for building identification and change detection between binary maps. Most of them are a research area and used for detection of land use change and informal settlements identification.

Informal settlements nature, characteristics and identification techniques will be studied and reviewed to understand the nature, cause, characteristics and legal issues of informal settlements.

The applications of cadastral map and remote sensing will also be reviewed to understand how they can be used and integrated to identify informal settlement. Informal settlement identification using remote sensing imageries and GIS will be studied and related works will also be reviewed to understand how to identify informal settlements. In addition, settlement identifications from high resolution remote sensing imageries will be studied to determine the approach for settlement detection. Building identification techniques will be studied and reviewed to understand how to identify built up area from remote sensing imageries and some of them will be adopted for our work. The concept of change detection and techniques of change detection will also be studied and reviewed.

1.5.2 Data Collection

Designing of informal settlement identification using remote sensing and cadastral map architecture for the case of Addis Ababa is the main aim of the work. To achieve this objective and other specific objectives of the work, aerial photograph of the initial reference time (1992) and target reference time (2010) will be collected from Ethiopian Mapping Agency and cadastral map of the study area will also be collected from Yeka sub-city Integrated Land Information Management Center.

1.5.3 Analysis and Design

To design the model of informal settlement identification, different identification system models and settlement identification system models developed before will be studied. To successfully accomplish our system implementation, programming language software and GIS software will be used.

1.5.4 Evaluation

Manually interpreted informal built up areas and identified informal settlements will be used to evaluate the system performance. By comparing manually interpreted informal built up areas and informal settlements we will evaluate the system performance of the developed model. Additionally the building identification module will also be evaluated using the manually interpreted building polygons and automatically produced from the system. Domain experts will be involved to judge the relevancy of the system. Finally, the conclusions and recommendations will be driven from the evaluation results.

1.6 Application of Results

- The purpose of this study is to identify, quantify and analyze informal settlements in Addis Ababa between initial and target reference time to contribute in the urban land, environmental management and monitoring plan. Therefore, it is expected to provide basic information on the status of informal settlement using automatic process. It is also expected to identify the settlement growth.
- Assist environmentalists, regional and urban planners to consider the potential of aerial photographs and cadastral map for monitoring and planning urban environment.
- Provide elements for long term bench-mark monitoring and observation relating to informal settlements and construction.
- Provide a base line for eventual research follow up, by identifying specific and important topics that should be looked in greater detail for those who are interested in the area.

1.7 Organization of the Thesis

The rest of the thesis is organized as follows. Chapter Two discusses literature review of informal settlement, aerial photograph, remote sensing, GIS, cadastral map and change detection. Furthermore, current practices in informal settlement and construction and description of the study area are discussed in this Chapter. Chapter Three discusses related works of building identification from aerial photograph and informal settlement identification using remote sensing and GIS. Chapter Four presents a discussion on the architecture of the proposed system, function of each components and their relation. The implementation detail of the system such as tools, algorithms, techniques and methods used to develop the system are described in Chapter Five. Chapter Six presents the experiments, evaluation and results analysis obtained from the proposed system along with their interpretations and the reasons behind each of the results. Finally, Chapter Seven concludes the thesis with the conclusion of the research, contribution of the work, recommendations, and future research directions.

CHAPTER TWO

LITERATURE REVIEW

In this Chapter, core concepts related to the work are reviewed. The concept of informal settlement, remote sensing, GIS, cadastral map, land use map and change detection have been reviewed. Description of the case study area, physical structure of Addis Ababa, informal settlements in Addis Ababa and current trends in informal settlement identification in Addis Ababa have been also reviewed in this chapter. It is the basis to devise the methods and techniques for the design of the desired informal settlement and building construction identification architecture.

2.1 Informal Settlement

Informal settlements are mainly the common phenomenon which occur in developing countries. These settlements are typically the result of illegal characters of citizens caused by an urgent need for shelter by urban low income dwellers. A combination of social, economic, legal, and administrative parameters lead, in several countries, to the stage of unplanned development and to the creation of a considerable number of informal uses of the land or construction [3].

According to United Nations (UNSTAT in [29]) informal settlement is defined as:

- "*Areas where groups of housing units have been constructed on land that the occupants have no legal claim to, or occupy illegally"*
- *"Unplanned settlements and areas where housing is not in compliance with current planning and building regulations (unauthorized housing)"*.

Informal settlements are not landless people but those occupying the government and public lands. They are socially accepted but do not have the legal right. *Informal*, or *spontaneous settlements* are settlements whereby persons, or *squatters*, assert land rights to or occupy for exploitation land which is not registered in their names, or government land, or land legally owned by other individuals. Squatters are people who occupy land or buildings without the explicit permission of the owner [13].

Factors that have led to the expanding of informal settlements in developing countries, most particularly in Africa, are inability of the government to define a clear and long-term land and housing policy, massive rural-urban migration, poverty and unequal distribution of wealth, poor land delivery systems and political instability [27]. Unclear municipal boundaries and overlapping administrative responsibilities, deficits in manpower, lack of finance and technical equipment are additional causes of informal settlements [19].

Informal settlements in most developing countries are due to massive migration from rural areas to cities where the majority of the new urban dwellers settle in non-regularized areas [14]. Another important factor that helps to explain the proliferation of slums is the rigidity of urban planning regulations associated with other factors such as poor governance, corruption and nepotism, which all lead to a severe shortage of land and urban housing, squatting, and infringements of building regulations [27].

Informal settlements are a reality and their rapid growth is one of the major challenges for authorities in providing essential services. This reality has appeared while the world economy has shown a global decline, leaving most of the least developed countries with fewer and fewer resources available to survive with the exponential growth of the population, unable to address their needs for basic infrastructures, like water, waste removal, energy, education and health care facilities [3,13].

Informal settlements are outstep in marginal of governmentally monitoring land plots such as transportation networks, near industrial areas, market places, forest area, riverbanks, abandoned or vacant plots, dumping grounds, etc. One of the fundamental difficulties that authorities face when planning a response to the formation and growth of informal settlements is lack of spatial and temporal data to assist in recognizing and quantifying the understanding of their pattern. As a result of these difficulties, informal settlements are often not spatially documented. There are no maps indicating the position, pattern, size, complexity and influence on others [8]

Informal settlements and expansion are costly in terms of time and manpower in access using surveys and also in some situation it may be dangerous for official enumerators to do house to house measurements. There are several possible ways of identifying about settlements status. One technique is integration of high resolution remote sensing images with existing land use maps that makes easy for the identification of settlements and their mapping [3, 8].

In Addis Ababa, informal settlements are not only poverty driven. For example middle-class households have illegally occupied the peripheral areas of western Addis Ababa over the past 10 years (1995 to 2005). Squatter settlements in Addis Ababa have rather poor access to basic urban services, including access roads and utilities, due to a combination of their peripheral location and recent establishment [17].

2.2 Aerial Photographs and Remote Sensing Image

Remote sensing refers to acquiring information about an object without touching the object itself. The sensor and target are located remotely apart and the electromagnetic radiation serves as a link between sensor and the object [3]. According to American Society of Photogrammetry, the purpose of remote sensing is to produce conventional maps, thematic maps, resource surveys, etc. in the fields of agriculture, archaeology, forestry, geography, geology and others [3].

Remote sensing is defined as a means of sensing earth"s surface from space by making use of the properties of electromagnetic wave emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resource management, land use and the protection of the environment. It has also the capability of providing large amount of data of the whole earth and also very frequently [14].

Aerial photographs have long been employed as a tool in urban analysis. City planning has been largely confined to aerial photography. It is being used for generation of base maps and other thematic maps for urban areas as it is proved to be cost and time effective and reliable. Wealth of information pertaining to land features, land use, built up areas, city structure, physical aspects of environment, etc., are available from the aerial photography. Various types of cameras and sensors (black and white, color, color infrared) are used for aerial photography [16].

A remote sensing device records response which is based on many characteristics of the land surface, including natural and artificial cover. An interpreter uses the element of tone, texture, pattern, shape, size, shadow, site and association to derive information about land cover [16, 22].

Due to the complexity and heterogeneous nature of urban land use, several studies have shown that high spatial resolution imageries are required to acquire all necessary land cover classes in urban environment. It is an asset for urban land use/cover researchers. Since 2000, data from a very high spatial resolution space born satellite have been available for various applications [16].

2.3 Geographic Information System (GIS)

International Training Centre (ITC), defined Geographic Information System (GIS) as a computerized system that facilitates the phases of data entry, data analysis and data presentation especially in cases when we are dealing with geo referenced data [3]. GIS is a set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purpose [4]. GIS as a computer based system provides four sets of capabilities to handle geo referenced data, data input, data management (data storage and retrieval), manipulation analysis and data output [12]. GIS draws on concepts and ideas from many different disciplines, such as cartography, cognitive science, computer science, engineering, environmental sciences, geodesy, landscape architecture, law, photogrammetry, public policy, remote sensing, statistics and surveying [3].

2.4 Cadastral Map

Information on land and possibilities for their optimal use is essential for planning and implementation of geographic information systems to meet the increasing demands for basic human needs. A typical land information system is cadaster. Cadastral systems are parcel based land information systems important in basics of land legality, land market, development and other economic activities. Land parcel is the basic unit for access and control of the land, land use decision and others [31].

A cadaster system refers to a parcel based land information system containing a record of properties in land, ownership, land use and area details. A cadastral map is the fundamental component of cadastral system that shows the relative location of all parcels in a given village or district. They commonly range from scales of 1:4000 to 1:8000 [11]. Some of main users of cadastral system are Citizens, Businesses, Economic Development Committee, Unit of Agrarian Development, Architecture and Town Panning, Federal and Regional Court, Federal Registration Service and Federal and Regional Tax Service [32].

An urban cadastral system contains not only parcel contour lines but also technical details of the region and also it should be complete and up-to-date. Various countries are also devoted in preparing digital, up-to-date, complete and easy accessible cadastral database and information of various aspects in the urban areas, because of its importance for developmental planning decisions and monitoring city growth for government officials and urban planners [34].

Review show that cadastral maps are not unique in nature. In urban land management some of the advantages of cadastral map are stated below [4, 6, 13, 31, 32]:

- Improvement in land and property on land taxes collection and estimation;
- Improvement in monitoring and analysis of land and property on land;
- Integrate different records, for instance land ownership, land use and land value with socio-economic and environmental data;
- Support infrastructure distribution management such as road, water, sewerage, electricity, street lights, and telephones;
- Provide better estimates of the value of land for taxation;
- Helps in border conflict resolution among the land holders;
- Helps in disaster and risk assessment;
- Assist in the allocation and monitoring permits to building on land;
- Identifying informal settlements;
- Important to control the land from illegal and corrupted activities;
- Important for the regularization/upgrading of informal settlements and
- Improve decision making.

A cadastral system usually includes two sets of data: cadastral data and parcel data. Cadastral data in urban areas may include the owner"s name, address, land-use code, assessed value, tax status, legal description, and recent sale price and date. Parcel data represents the boundaries of the land parcels, each with a parcel identification number, site address, tax map number and parcel number. In urban land management, attribute information have several roles in making a cadastral system a complete land information system based on users demand and decision making for officials and others [13, 32].

2.5 Land Use

Land use is the purpose for which the land is being used [4]. Land use is generally based on land cover. Land cover is represented by natural and artificial compositions covering the earth"s surface at a certain location [4]. It is repetitive coverage in map format, so that remote sensing imageries are feasible source of land cover at local, regional and global scales. This makes possibility of obtaining up-to-date land use and land cover data [13].

Land use and land cover information are important in managing natural resources, monitoring environmental changes and evaluation of planning and others. Land use information in urban areas also assists in monitoring the dynamics of land use resulting out of changing demands of settlements due to increasing population [21]. Urbanization and informal settlements lead to the change in the existing land use information. Therefore analyzing the change in existing land use information can enable in identification of new settlements, informal settlement and the effect of urbanization [1].

2.6 Change Detection

Urbanization and informal settlement resulted in increased land consumption and modification and alterations in land management database. The changes occur on land use, land cover and legal status of the land information. It is, therefore, necessary for a study such as this to be carried out in associated problems of a growing and expanding illegality in cities like many others in the world.

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times [2]. In remote sensing applications, change detection is an important process in monitoring and managing natural resources and urban development because of the possibility of accessing spatial and temporal data [5].

There are some aspects of change detection, which are important when monitoring resources which are detecting the changes that have occurred, identifying the nature of the change, measuring the area extent of the change and assessing the spatial pattern of the change. Several kinds of change analysis or detection methodologies are available; the choice of the appropriate methodology is dependent on the goal of the project and the existing map [5].

2.7 Description of the Case Study Area

There were three main factors for Addis Ababa city to stay as the capital city of Ethiopia (since many cities have been capital cities in the history of Ethiopia): the introduction of eucalyptus (a tree that grows very fast and provides a lot of wood for energy and cooking), the proclamation for legalizing private ownership of urban land in 1907 and the completion, mainly by the French, of the Addis Ababa – Djibouti railway in 1917 [20].

Today, Addis Ababa is a rapidly expanding city. Especially, the creation of new housing and industrial areas makes Addis Ababa one of the largest cities in sub-Saharan Africa [20]. With the headquarters of the African Union and the United Nations Economic Committee for Africa both based in this capital, it is of unique importance for African diplomacy. The regional headquarters of UNDP, UNICEF, UNHCR are also based in Addis Ababa.

Addis Ababa, the capital city, attracts 90,000 to 120,000 new residents every year, mainly due to net immigration (UN-Habitat in [30]). Table 2.1 shows the total population of Addis Ababa and the average annual growth rate from 1910 -2007.

Table 2.1: Total Population of Addis Ababa between 1910- 2007

Year	Total Population	Average annual growth rate (%)
1910	65000	-
1935	100,000	1.72
1952	317,925	6.8
1961	443,728	3.7
1970	750,530	5.84
1976	1,099,851	6.37
1984	1,423,111	3.22
1994	2,112,737	3.95
2000	2,495,000	2.77
2004	2,805,000	2.93
2007	3,384,569	3.8

(Source: Mesfin Tadesse Bekalo in [21])

Addis Ababa city is a selected case study to demonstrate the application of informal settlement identification methodology using high resolution multi-temporal aerial photographs and cadastral map. The city is divided into ten administrative sub-cities and 116 administrative woredas. It is the largest city in Ethiopia with a population of 3,384,569 people and annual growth rate of 3.8 peoples (according to the 2007 population census). It has a surface area of 527 sq.km. Its coordinates are 9°1'48" N and 38°44'24" E in DMS (Degrees Minutes Seconds). It is located at an average elevation of 2,355meters above sea level. Figure 2.1 shows the location map of Addis Ababa city.

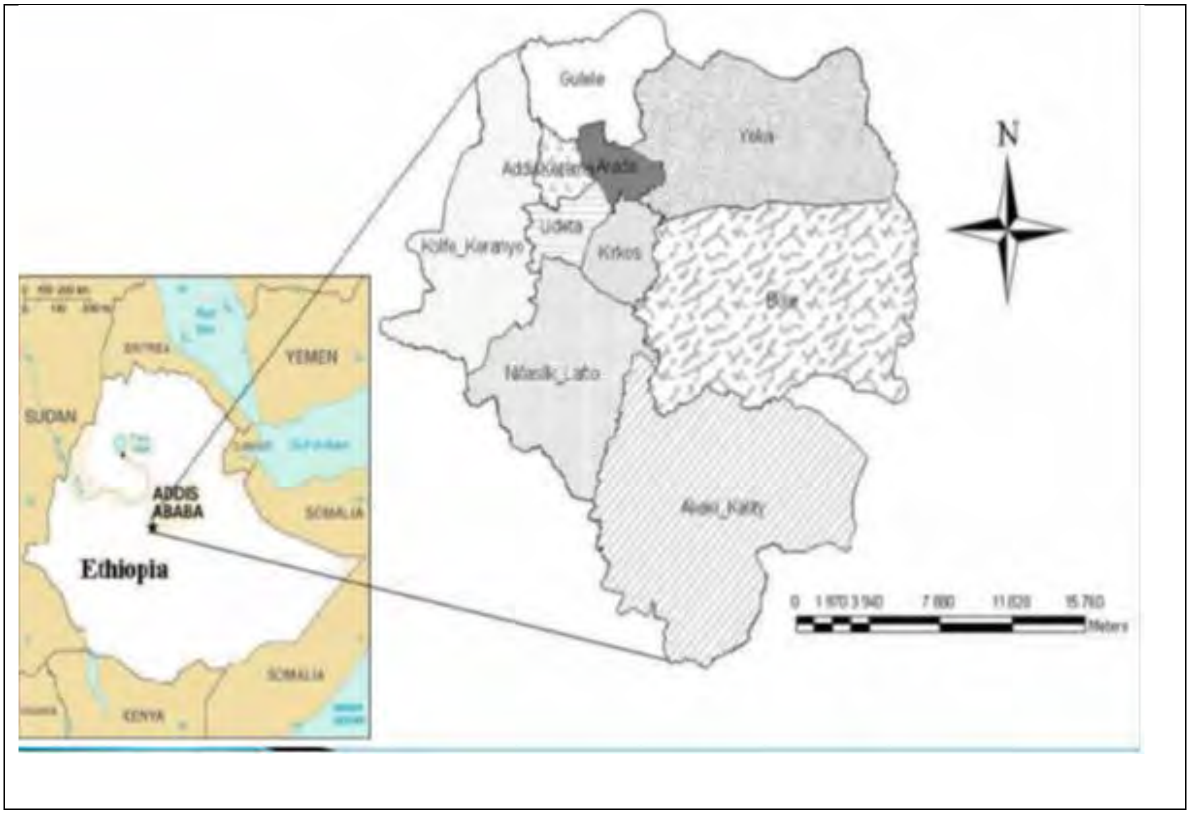

Figure 2.1: Location Map of the Study Area

2.8 Addis Ababa City Physical Structure

As an indigenous urban settlement, Addis Ababa initially expanded without any formal planning or control. The earliest settlements developed randomly around the king"s palace and the camps *(„sefers')* of his generals *(rases)* and other dignitaries. It appears that just like the king, the generals live surrounded by the ranks and files of their subordinates. Sizable vacant spaces separated the residences of these dignitaries from those of their subordinates. This original settlement pattern eventually led to the gradual filling up of those vacant spaces and the emergence of a residential structure where the wealthy lived side by side with the poor [20].

The mixed residential structure that began in those days was not changed by the changes that took as the country opened up to Western civilization in the early 20th century and subsequently during the short-lived Italian occupation.

Over the last three decades, a few predominantly high-income, residential areas have emerged, especially in the Bole and Old Airport areas. A new upper middle class residential area also seems to be in the making in the eastern peripheries of the city. Apart from these few changes

Addis Ababa doesn"t show the degree of separation between housing classes, which is the common features in other major cities in the developing world. All over the city, the poor, the middle-income earners and the rich live side by side.

Today, high-rise apartment and office blocks are being built in fronts of the main streets in Addis Ababa give a rather confusing belief of a well-built city. Roadside buildings often effectively mask the predominantly low standards of most housing units and apparently well-integrated residential structure. Most of the capital"s residents live in poorly constructed and inadequately serviced substandard housing occupation to meet the shelter requirements of a rapidly growing and overwhelmingly poor population [36].

2.9 Physical Expansion Trend in Addis Ababa

The rapid growth of population of the city has put great pressure on the demand for urban land. In response to this demand, efforts are being made by the city government to incorporate the peripheral areas of the city, which is resulting in accelerating the expansion of the built-up area of the city [21]. Accordingly, Addis Ababa has experienced rapid physical expansion (Table 2.2).

Table 2.2: Physical Growth of Addis Ababa City Built-up area (1886-2000)

Period	Average covered (hectares)	Total Built-up area (hectares)	Annual growth rate (%)
1886-1936	1863.13	1863.13	-
1937-1975	4186.87	6050	3.1
1978-1985	4788	10,838	6.0
1986-1995	2925.3	13,763.3	2.4
1996-2000	909.4	14,672.7	1.6

(Source: Mesfin Tadesse Bekalo in [21])

The early development of the city from 1886 to 1936 was characterized by fragmented settlements. Following the Italian occupation in 1937, the process of physical development of Addis Ababa was characterized by infill development and consolidation of the former fragmented settlements [20]. The physical expansion of the built-up area of the city during the period 1937 to 1975 was characterized by a compact type of development. From 1976 to 1985, the built-up area increased by 4788 hectares, thus increasing the cumulative total to 10,838 hectares [20].

The next period of physical expansion of the city was between 1986 and 1995, when the built-up area expanded by 2925.3 hectares, increasing the cumulative total to 13,763.3 hectares. Simultaneously, horizontal expansion took place in all peripheral areas of the city, where both legal and informal settlements were established. Out of the total 94,135 housing units built in the city between 1984 and 1994, 15.7% (14,794 housing units) were built illegally [20].

During the most recent period of physical expansion, between 1996 and 2000, the physical built-up area of Addis Ababa increased by 909.4 hectares, reaching a cumulative total of 14,672.7 hectares. Expansion of the city was characterized by the development of scattered and fragmented settlements in the peripheral areas of the city, with both legal residents and squatters. In 2000, Addis Ababa had an estimated total of 60,000 housing units with squatter settlements. This figure accounted for 20% of the total housing stock of the city and the total area occupied by squatter settlements was estimated at 13.6% of the total built-up area [20].

2.10 Informal Settlements in Addis Ababa

Informal settlement in Addis Ababa city is a common phenomenon. Informal settlement is locally called „*yechereka bet*". In Addis Ababa city, new informal settlements are found in peri-urban woredas and the old ones are usually found in the central and sub-central parts of the city [20].

One thing that makes squatter settlements somewhat different in the case of Addis Ababa is that they are not poverty-driven. As research by Minweylet Melese in [17] shows, mainly middle-class households have illegally occupied the peripheral areas of western Addis Ababa in the years (1995 -2005). Squatter settlements in Addis Ababa have rather poor access to basic urban services, including access to roads and utilities, due to a combination of their peripheral location and recent establishment.

Due to the city‟s residential structure, the slums in Addis Ababa are not the exclusive preserve of the poor: an urban assessment study completed in early 2005 suggested that about 80 percent of Addis Ababa‟s residential areas were slums. Physical deterioration of housing, overcrowding, high density, poor access, and lack of infrastructure services characterize the 80% or more of Addis Ababa‟s that are generally described as "slums" [26].

Yeka sub-city Woreda 10 and 11, which are peri-urban woredas, located northeast of the city are areas used to test the model of our study. According to the woredas administrations, informal settlements are highly expanded. The informal settlements in these woredas are situated far from the main roads and are covered by eucalyptus plantation. This strategic situations make them far less visible to municipal and woredas officials for long times and opened good opportunity for their expansion.

2.11 Informal Settlement and Building Construction Identification Current Practice in Addis Ababa

In Addis Ababa city land related issues and information are governed by Addis Ababa City Land and Land Related Administration Sector (LLRAS). LLRAS of Addis Ababa is organized into permit Authority, Renewal project office and Information Institute as shown in Figure 2.2 [36]. Exactly the same administration configuration is also set up for the ten sub-cities and the 116 woredas of Addis Ababa.

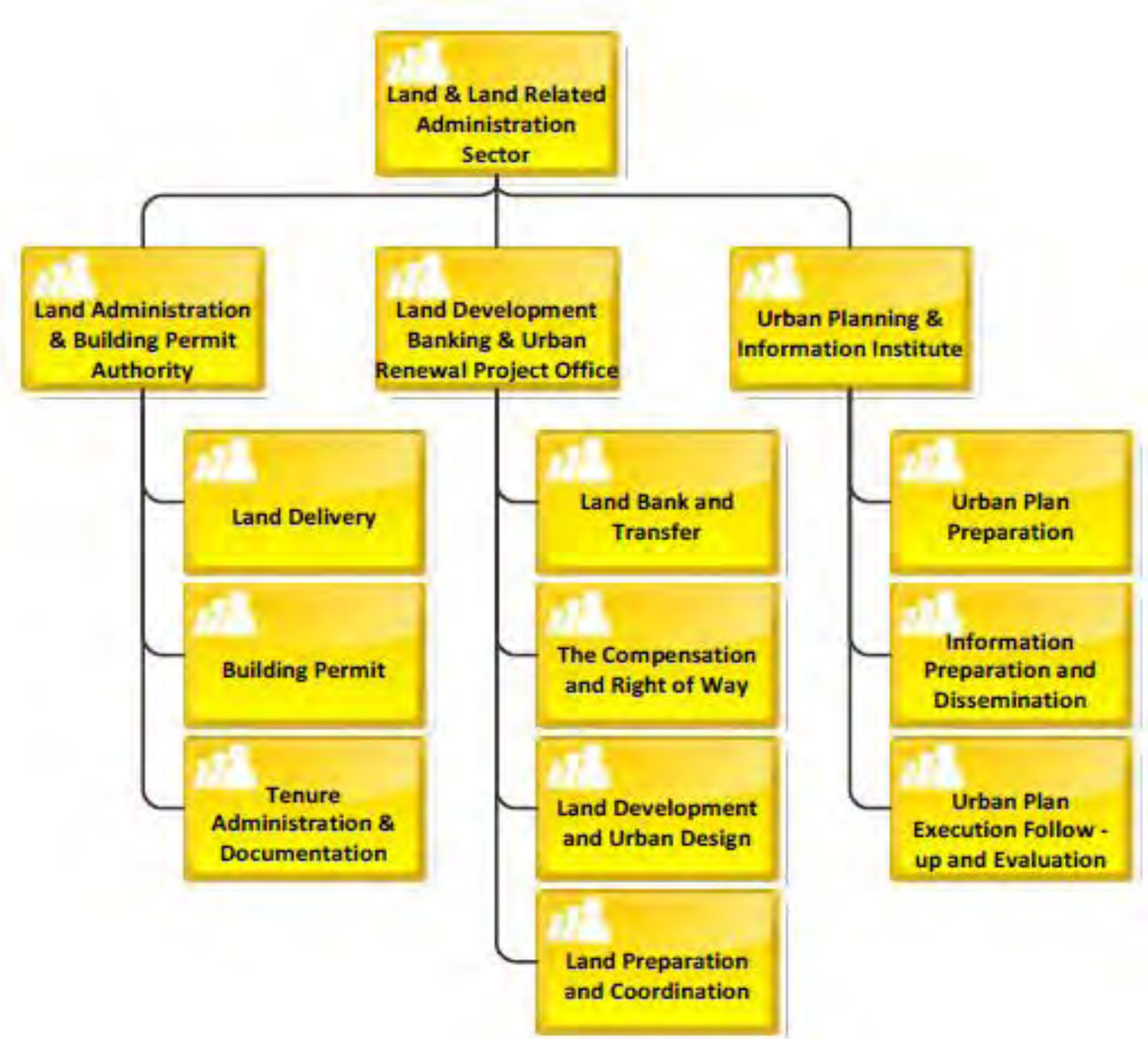

Figure 2.2: Organizational Structure of Addis Ababa City LLRAS

Real property registrations are carried out by the land administration and building permit (LABPA) and the registration is based on title deeds registered in several books and on the cadastral map. The title deeds are the official record of the rights on land. Figure 2.3 shows a sample of an existing title deed [36].

Figure 2.3: Sample of an Existing Title Deed

Currently, all formal constructions in Addis Ababa are monitored and permitted by land administration and buildings permit Authority. Additionally Addis Ababa city administration hired a large number of people in each woreda, who rover around the woredas, to control informal construction. These employees check the title deed and building permit document to control the informal settlement and construction. Currently, new informal settlement and constructions are identified by employees hired in each woredas. They are locally called "*Afresh Gibrehil*". However, most constructions take place in the night time. Hence, full control could not be possible even in central woredas let alone in peri-urban fringes.

CHAPTER THREE

RELATED WORK

In this Chapter, we have reviewed and discussed some related works on building identification from aerial photograph and informal settlement identification using remote sensing and GIS. Building identification works are reviewed from the point of view of features and methodology used to identify. Informal settlement and construction identification works are reviewed from the point of view of the included input maps, maps resolution, approaches used, methods of image segmentation, settlement classification, and the accuracy of the identification system.

3.1 Building Identification from High Resolution Remote Sensing Images

The methods that can be applied to detect settlement areas in satellite images depend on the resolution of these images. In images having a resolution better than about 2.5 m, a settlement is decomposed into buildings, roads, vegetation, and other objects [23].

Most building detection from aerial imagery approaches can be classified according to whether they are automatic or supervised (require a training phase) and whether they extract geometric features such as lines, corners, *etc.* or are area based. There are of some exceptions used hybrid methods employ both geometric features and areas or have both automatic phases and semiautomatic supervised phases [23].

Lefevere *et al.* in [22] propose an area based automatic building detection from aerial image approach which employs morphological filtering. First, binary images are created by clustering the aerial image‟s grey scale histogram. Then, multiple clusters are fused together and added to the original set of binary images. Finally, morphological opening, followed by the hit or miss transform and then geodesic reconstruction are performed for building detection. Their approach realized a pixel level completeness of 63.6% and a pixel level correctness of 79.4%. While the authors approach is automatic, it unfortunately implements the assumption that buildings are square or rectangular. The authors compute a two-dimensional geometry of the binary images varying the width and length of the rectangular window. Because they do not vary the orientation of the window, they assume the rectilinear buildings are all parallel with one another and that the image has been rotated so that the sides of the buildings are parallel with the edges of the image.

Liu and Prinet in [24] used a feature and area based approach coupled with a probability function to identify building regions. Their algorithm starts out segmenting the image. Then a set of features (such as contour edges, shadow ratios, shape features, region entropy, etc.) is identified in each region. Then, the probability function calculates the confidence value that the given region is in fact a region corresponding to building. Some of the parameters of the probability function are determined from a training set where buildings were manually identified. They reported a completeness and correctness of 94.5% and 83.4%, respectively, on a data set having 277 buildings.

Shorter and Kasparis in [23], proposed a more general assumption that buildings tend to have convex hull rooftop sections to identify buildings. The method is unsupervised, that is, no parameter adjustment is done during the algorithm"s execution. Their work first segments the image into different regions using watershed segmentation and the solidity of each region is measured. Finally, the threshold was applied on the solidity of each region to filter out buildings. They reported a pixel level completeness and correctness of 78.7% and 51.6% respectively for 2643 buildings from 15cm resolution aerial photograph. Their work remove roads and surrounding land scape using solidity calculation considering they have identified as a single region and have low solidity values. However, these results in broken roads mistakenly identified as buildings. In addition, large size landscapes which have solidity above the threshold value are also mistakenly identified as buildings, which are the most common phenomena.

3.2 Informal Settlement Identification using Remote Sensing and GIS

Hofmann *et al.* in [10], demonstrated how informal settlements can be detected from very high resolution satellite image data using an object based approach of image analysis for Rio De Janeiro. They indicated informal settlement detection in a context of high inner-structural heterogeneity characteristics. Red roofs, small shadows/dark objects, bright small roofs/objects and vegetation in relation to settlement coverage are indications of informal settlements in this work. The overall accuracy for the classification before applying the iterative approach was 47%. After applying the iterative process the overall accuracy increased to 68%. They concluded that high resolution data is well suited to detect informal settlement areas.

Stasolla and Gamba in [7] used SPOT-5 images with 2.5m spatial resolution to detect informal settlements (refugee camps) in Darfur, Sudan. They developed a semi-automatic procedure adopting an unsupervised approach that allows detecting, with high precision, the boundaries and the extent of the settlements, both formal and informal, and, to some extent; were able to separate those two classes based on differing building densities. Once the position of the settlement had been detected, the next step in the procedure was to identify different building densities to discriminate the city core from the refugee camps. The inability to differentiate single buildings due to scale and resolution, and similar textural properties between certain vegetation classes and settlements leading to incorrect classification were cited as limitations.

Hurskainen and Pellikka in [15] presented change detection of informal settlements using multi-temporal aerial photographs in the case of Voi, Se-kenya. Black and white and true-color aerial photography from 2004, 1993 and 1985 were used for studies of growth and change of informal settlements. Scale, shape and compactness parameters were adjusted and thematic layers were incorporated to improve the classification accuracy. *eCognition* software package is used for segmentation and classification to built-up and non-built areas and post classification change detection for settlement comparison. Results showed that iron sheet roofs were segmented and classified with 95% accuracy. Limitations encountered in case of grey tones roofs which are not spectrally distinct enough to separate them from the background.

Paudyal in [13] made a study about the application of high resolution satellite with cadastral maps for identification of informal settlements of Nepal. In this study, three data sources were used; corona image of 1967, cadastral Maps, IKONOS imagery (Fused to 1m) and attribute data provided from the community groups. Corona images of 1967 have been used to identify the initial vacant area of the study area. The author concluded that the integration of cadastral maps with high resolution satellite imagery will be the best tool for the identification and mapping of informal settlement.

Kefale Alemie *et al.* in [8] developed a semi- automatic based informal settlement detection using remote sensing imagery, land use map, cadastral map, and GPS surveying for Bahirdar, Ethiopia. GeoEye 2012 with 0.5m spatial resolution and QuickBird 2004 with 0.65m spatial resolution remote sensing imageries were used. GPS was employed to capture the boundaries of informal settlement for the spatial data. The image analysis techniques applied were including supervised image segmentation and semi-automatic object extraction. The existing land use and cadastral maps were used for the spatial analysis of informal settlements.

Muli in [3] used remote sensing and geographic information systems (GIS) for detecting a change in the informal settlements of Kawangware, Nairobi from1990 to 2010. The author developed a GIS-based integrated approach to modeling and prediction of urban growth in terms of land use change. Aerial photograph of 1990, quick bird imageries of 2000 and 2010 and population data were used in the creation of a model of each land use category and settlement category. Supervised image classification was used for satellite image classification.

Igbokwe *et al.* in [19] used remote sensing and GIS for identification of urban sprawl for case study of Onitsha and its environs in southeast Nigeria. Their work investigated analyzed and modeled urban sprawl by considering the built-up areas as the key feature of sprawl. They utilized supervised classification approach to derive six land cover maps from Digitized Topographical Map, NigeriaSat-1 and LANDSAT ETM+ multi-spectral images for the years 1964, 2004 and 2006 respectively. They reported that urban area increased by 56.15% between 1964 and 2006 and 33.96% between 2004 and 2006.

Karanja and Lohmann in [33] developed knowledge based unplanned settlement identification. The knowledge models used are derived from multi-temporal and spectral remote sensing images and building plans which show among other information the extent and permitted type of use. The method employed object, structural and spectral information from two remotely sensed data at different periods to generate two classes namely built up (developed) and reserved (non-developed) for each period within an expert classification environment. This information is then combined with a plan of future land use as temporal knowledge to predict areas designated for development. The concept developed here cannot be applied to situations in developing countries, unless the knowledge base would have to be customized so as to reflect the real situation in a developing country since the urban structure differs from that of the developed countries.

3.3 Summary

From these works we understand that high resolution remote sensing imageries are the best tool in informal settlement identification. The integration of remote sensing images and GIS are also applicable in informal settlement identification. The first two approaches discussed (Hofmann, and Stasolla and Gamba) indicated that high inner-structural heterogeneity, size and building densities characteristics are the main features in differentiating informal settlements. Such patterns are not applicable to indigenous cities such as Addis Ababa on which informal settlements are not the case of economic factors, most part of the city are densely constructed and fail to differentiate housing classes as discussed in the physical structure of Addis Ababa in Chapter-2 Section 2.8. These approaches also do not consider well-constructed informal buildings as informal settlements.

The work by Hurskainen and Pellikka in [15], Kefale Alemie *et al.* in [8], Muli in [3], and Igbokwe *et al.* in [19], incorporate GIS map and remote sensing images. They have been used supervised image classification which requires a training data in the identification of informal settlement. Knowledge Model based approaches by Karanja and Lohmann in [33] are developed for informal settlement identification in case of planned city structure. The method is not appropriate for informal settlement identification in case of mixed settlement structure and indigenous city structure such of Addis Ababa city unless the knowledge base would have to be customized so as to reflect the real situation in a developing country.

CHAPTER FOUR

ARCHITECTURE OF INFORMAL SETTLEMENT AND CONSTRUCTION IDENTIFICATION MODEL

We first analyzed the problem of informal settlements and building construction in Addis Ababa, the proposed informal settlement and building construction identification model uses cadastral map and multi temporal aerial photographs as input and produces the informal settlements and building constructions. We present the general architectural design of the proposed informal settlement and construction identification using image processing techniques as shown in Figure 4.1. The main components of the system together with their subcomponents, and the interaction between each of them are described below.

4.1 Components of the System

Informal settlement and construction identification using change detection is composed of the following essential components: cadastral map labeling, geo-referencing the aerial photographs, building identification, built up area change detection and informal settlement identification as shown in Figure 4.1. Cadastral map labeling is used to create vector zone map that shows the permitted built up parcel of land using color labels. Building identification identifies buildings from the geo-referenced aerial maps in the early and late study periods and produces the binary map classified into built up and non-built up areas. Built up area change detection compares the two classified images in the initial and target reference times and extracts areas, which are constructed in the study period. Informal settlement identification finally identifies informal settlements using change detection between the change detected build up maps and the labeled cadastral map. In general the system takes multi-temporal aerial photographs and cadastral map as input and generates the identified informal built-up areas.

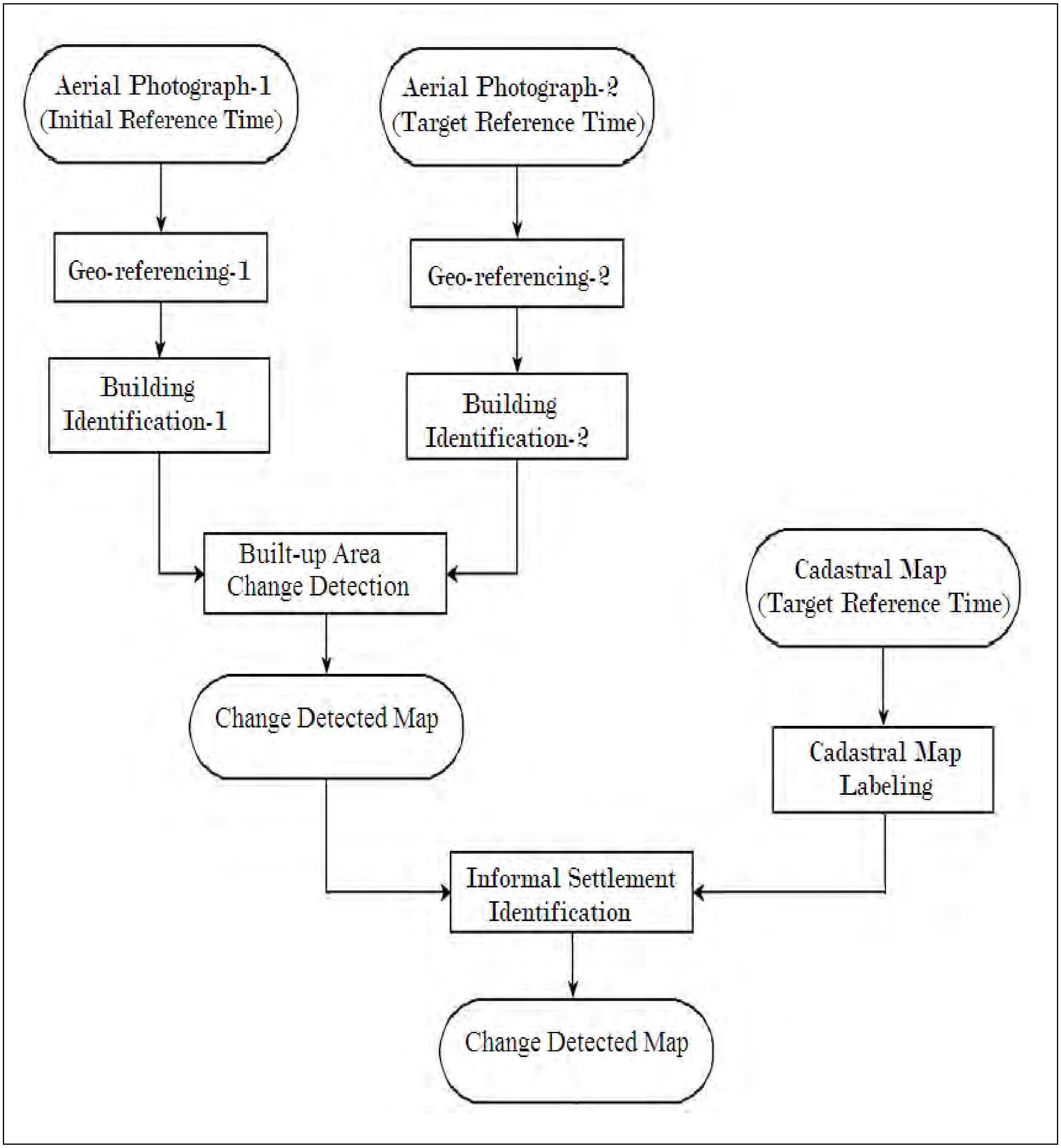

Figure 4.1: The General Architecture of Informal Settlement Identification using Change Detection

4.2 Cadastral Map Labeling

To identify the informal settlement and construction, first we should have information about the formal/legal built up parcels of land. Cadastral map is the officially approved map that contains vector map and attribute information. The labeled cadastral map visualizes permitted or legal build up parcels using colors labels. The main function of this component is to have a vector zone map that shows the permitted built up parcel of land. In the cadastral map each parcel of land has a unique identification codes which are used to combine the vector map and attribute information. The labeled cadastral map is created by combining the vector map and the land use attribute information using the parcel identification code.

4.3 Geo-referencing Aerial Photographs

In raster images like aerial photographs there is no geographic coordinate system established. Geo-reference is the process through which a digital map is associated with real geographical coordinates [10]. Geo-referencing is also defined as the process of establishing the geographical coordinates of certain points with great accuracy and their location on a digital map, while the remaining points are calculated automatically, based on transformation formulas [11]. As a pixel has size, it corresponds to an area on Earth.

Several ways can be applied to geo-reference the aerial photograph. One way is to geo-register an image by registering the image to an already geo-referenced map (base map) coordinate and creating a new "geo-referenced" image. This method uses ground control points which are identified in both input and base maps. Ground control points are used to register the aerial photograph (input) to an already geo-referenced map. Geo-referencing using registering an image to an already geo-referenced map coordinate includes an image registration using ground control points, applying a geometric transformation and creating a geo-reference metric. The geo-referenced labeled cadastral map exported from GIS software is the geo-referenced map in the process of geo-referencing of aerial photographs.

Image registration: enables geo-registration based on control point pairs that relate the input aerial photograph to the base labeled cadastral map. Control points are land marks that we found in both images, like a road intersection, or a natural feature.

Geometric transformation: geometrically transform the registered image in the base map. This can be done by creating an output bounding box for the registered image and transform the aerial image to an image that should fit just right within the output bounding box. The output bounding box can be created by predicting the corner location of the registered image, calculating the average pixel size of the input image (in map units) and by finding the centers of the upper left and lower right corner pixels.

4.4 Building Identification

Buildings are optimal set of settlement features [16]. One of the approaches in settlement identification from very high resolution remote sensing image is building identification. High resolution aerial photograph lends itself well to the extraction of spatial features in urban environments [23]. To identify informal settlements and construction from high resolution aerial photograph, first all buildings should be identified from the input aerial photographs.

Our building identification methodology is according to more general assumptions, which is buildings tend to have convex hull rooftop sections [23], rather than saying all buildings have parallel sides or right angle corners. Furthermore, many houses have a variety of different color roof tops. A convex hull is defined here as the minimum polygon which completely encompasses a given region. Our building identification component consists of image pre-processing, Image segmentation, solidity measurement, buildings candidate extraction, and morphological filtering. The architecture of building identification is shown in Figure 4.2 and its components and sub components are discussed below.

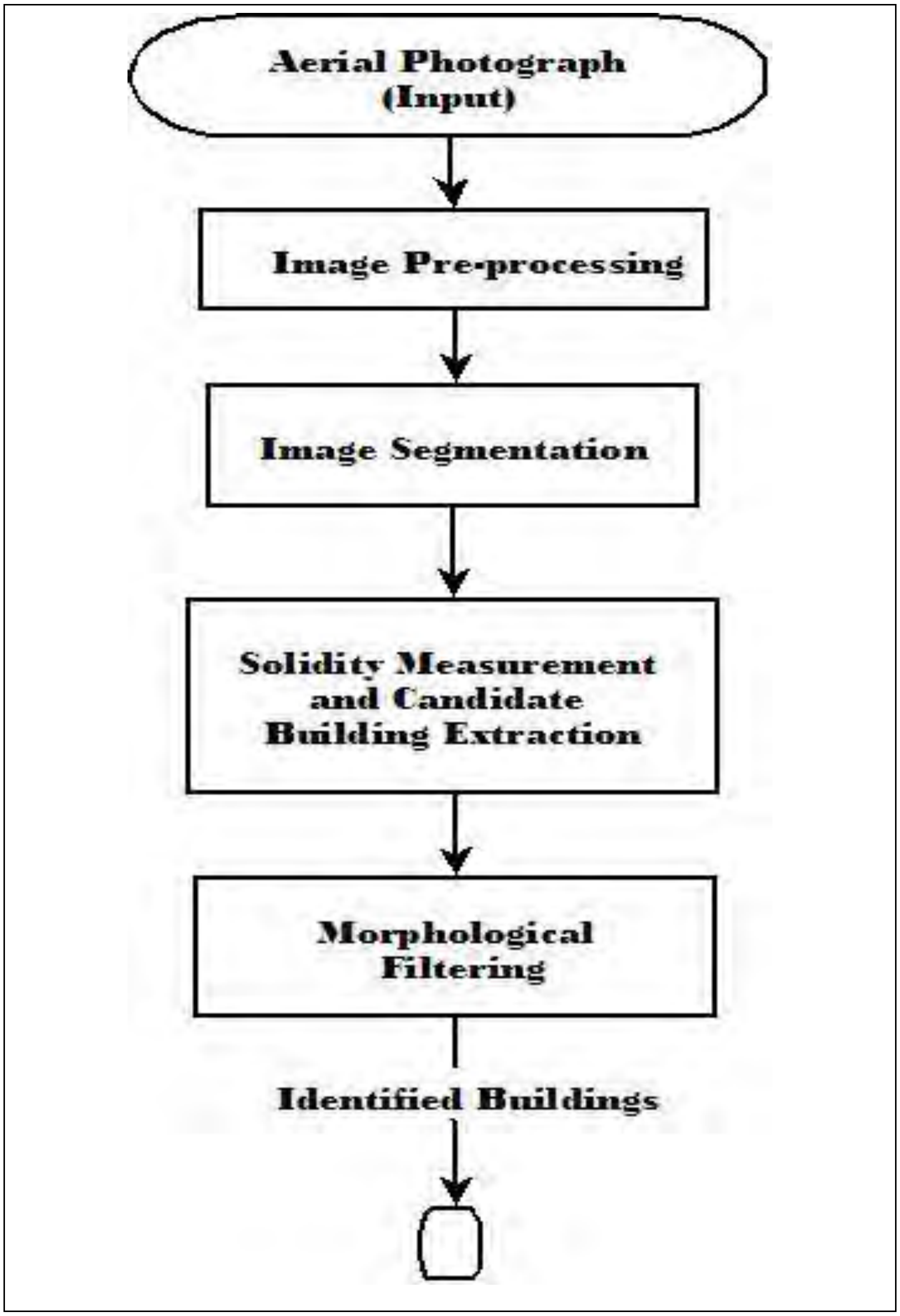

Figure 4.2: Building Identification Architecture

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4.4.1 Image Pre-Processing

The use of remote sensing image for settlement identification requires several pre-processing procedures. The goal of digital image pre-processing is to increase both the accuracy and the interpretability of the digital data during the image processing phase [19]. In our case pre-processing of raster images is necessary prior to segmentation. Most image processing tasks use smoothing operations to remove noise. Image smoothing operation is the processes used to reduce noise and/or to prepare images for further processing. This can be done using wiener filter, Wiener filter is 2-D adaptive noise-removal filtering defined as follows [2]:

$$\boldsymbol{\mu} = \frac{\mathbf{1}}{\boldsymbol{NM}} \sum_{\boldsymbol{n1},\boldsymbol{n2} \in \boldsymbol{\eta}} \boldsymbol{a}(\boldsymbol{n_1}, \boldsymbol{n_2})$$

$$\boldsymbol{\sigma^2} = \frac{\mathbf{1}}{\boldsymbol{NM}} \sum_{\boldsymbol{n_1},\boldsymbol{n_2} \ \epsilon \ \boldsymbol{\eta}} \boldsymbol{a^2} \ (\boldsymbol{n_1}, \boldsymbol{n_2}) - \boldsymbol{\mu^2}$$

where μ denotes the mean, NM denotes the size of the neighborhood matrix N by M, $a(n_1, n_2)$ denotes the value of the pixel in a position n_1, n_2, σ denotes the standard deviation.

Wiener filter then creates a filter using these estimates, ∈

$$\boldsymbol{b}(\boldsymbol{n_1}, \boldsymbol{n_2}) = \boldsymbol{\mu} + \frac{\boldsymbol{\sigma^2} - \boldsymbol{v^2}}{\boldsymbol{\sigma^2}} (\boldsymbol{a}(\boldsymbol{n_1}, \boldsymbol{n_2}) - \boldsymbol{\mu})$$

where, v^2 is the noise variance. If the noise variance is not given, wiener filter uses the average of all the local estimated variances.

4.4.2 Image Segmentation

Image segmentation is the process of partitioning a digital image into multiple segments. The goal of segmentation is to simplify and/or change the representation of an image into something that is more meaningful and easier to analyze [18]. Image segmentation is typically used to locate objects and boundaries in an image. More precisely image segmentation is the process of assigning a label to every pixel in an image such that pixels the same label share the same characteristics. The result of image segmentation is a set of segments that collectively cover the entire image [18].

Several general purpose algorithms and techniques have been developed for image segmentation. To be useful these techniques must typically be combined with a domain specific knowledge in order to effectively solve the domain‟s segmentation problems. There are several ways of image segmentation. One way is the transform method such as watershed segmentation.

Watershed is basins like land form defined by high points and ridge lines that descend into lower elevation and stream value. The aerial photograph should have to be processed to make it suitable for watershed transform. Our image segmentation component using watershed transform consists of image filtering by gradient, threshold gradient filter image, distance transform and watershed transform. The block diagram of image segmentation is shown in Figure 4.3 and its components and sub components are discussed below.

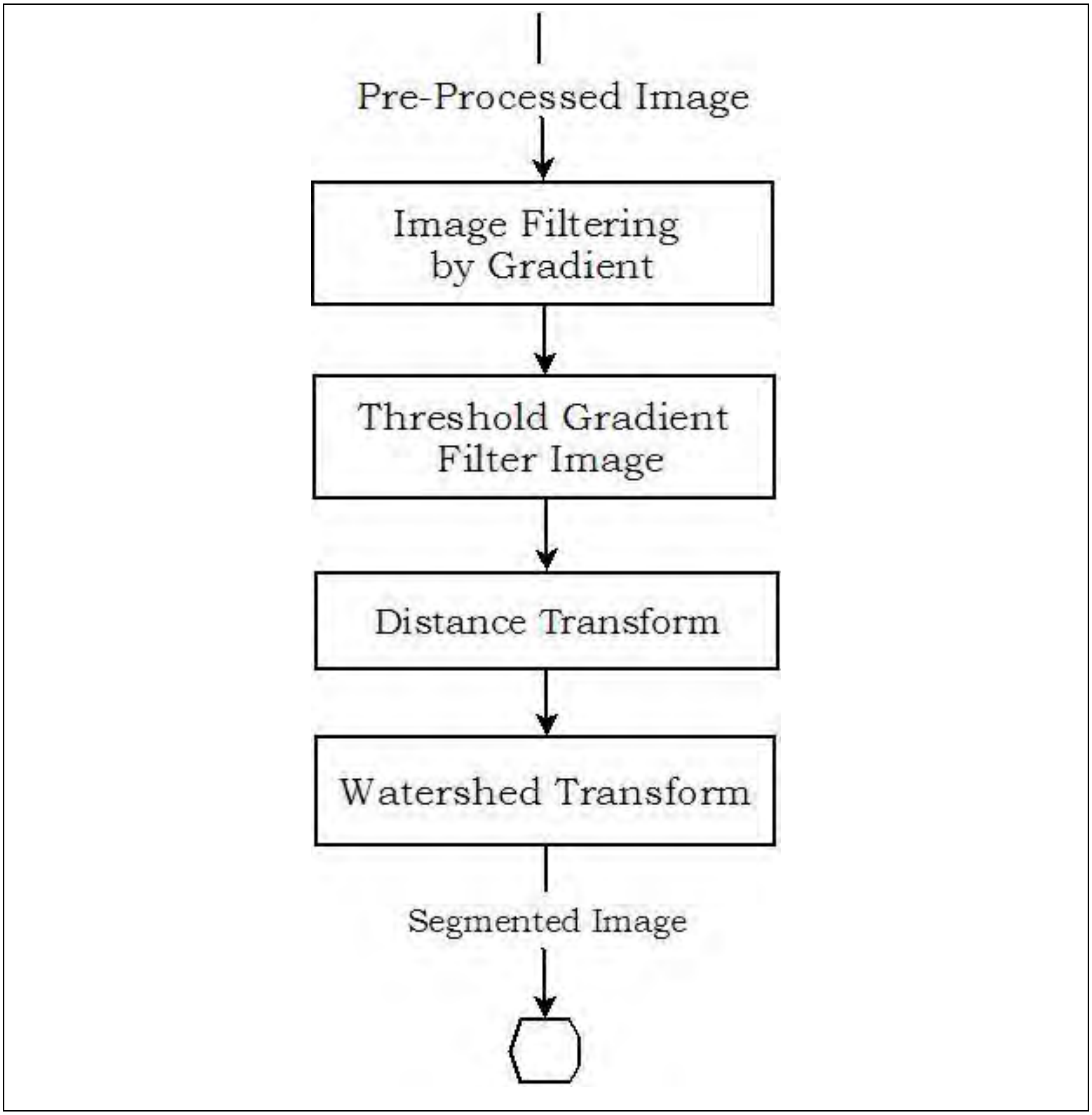

Figure 4.3: Block Diagram of Image Segmentation

a. Image Filtering by Gradient

To segment the image using watershed segmentation the first step we have to take is to find the catchment basins and watershed ridged lines, which represent boundary and segments respectively. Gradient filtration is a statistical measure of randomness that can be used to characterize the texture of the input image, which is better to discriminate heterogeneous areas and homogenous areas. Borders areas have high heterogeneity [23]. To extract these border areas gradient filtration can be applied. Since gradient is high at the borders of the objects and low (mostly) inside the objects [23], gradient filtration is responsible to extract the border areas or pixels, which may be building or other objects border. These border pixels will be used to find individual regions in the later procedures. Gradient filter such as entropy filter is used to produce gradient image, where each output pixel contains the entropy value of the 9-by-9 neighborhood around the corresponding pixel in the input image. Entropy is calculated as follows [23]:

$$\sum_{i=1}^{L} p(z_i).log_2(p(z_i))$$

where ***p(zi)*** is the number of occurrences the intensity ***zi*** has in the 9X9 neighborhood. So, image filtering using gradient filtration is an important component in the process of finding individual regions in an image.

b. Threshold Gradient Filter Image

Thresholding is a simple tool to separate objects from the background [29], the output of which is a binary/logical image. Working with a logical image reduces the complexity of the whole execution process as we deal with only two possible values (0 and 1). Threshold the gradient filter image is then used to extract high gradient areas which are border pixels and remove gradient below a threshold which is inside objects.

c. Distance Transformation

Distance transform is used to mark the foreground objects we want to segment. It is included here because it provides a metric or measure of the separation points in the image which are important to separate individual regions. The distance transformation calculates the distance between each pixel that is set to off (0) and the nearest none zero pixel for binary images. For instance, Figure 4.4 illustrates the Euclidian distance transform of a binary image [23]. The Euclidean distance is the straight-line distance between two pixels with the value of 1 unit in the horizontal and vertical direction and 1.4 diagonally

0	0	0
0	1	0
0	0	0

(A) Small image

1.4	1	1.4
1	0	1
1.4	1	1.4

(B) Distance transform image

Figure 4.4: Euclidian Distance Transform

d. Watershed Transform

Buildings and non-buildings are detected by measuring the solidity of their regions. The regions are obtained by watershed transform technique. Watershed transform is used to find separate regions in an image by separating touching objects. To separate touching objects watershed transform finds watershed ridge lines and catchment basins [35]. The catchment basins and watershed ridged lines are the indicators of the inside region (segment) and their boundary pixels respectively. Watershed transformation considers the gradient magnitude of an image as a topographic surface. Pixels having the highest gradient magnitude intensities correspond to watershed lines, which represent the region boundaries. The key behind watershed transform for segmentation is change the image into another image whose catchment basins are the objects we want to identify [35].

The watershed transform finds "catchment basins" and "watershed ridge lines" from the distance transform image by treating it as a surface where light pixels are high and they are indicators of catchment basins. Dark pixels are low and are indicators of watershed ridge lines. Finally, a watershed transform computes a label matrix for the segmented regions to identify individual regions.

4.4.3 Solidity Measurement and Candidate Buildings Extraction

Our building identification methodology is according to a more general assumption, that is buildings tend to have convex hull rooftop sections. To identify objects which tend to have convex hull, the solidity should have to be measured. Solidity is the ratio of region and convex hull. A convex hull is defined here as the minimum polygon which completely encompasses a given region. The upper limit of the solidity can be exactly one (the region itself is a convex hull) and the lower limit can get infinitely close to 0. Therefore, the more convex the region exterior is, the higher its solidity. This approach implements the assumption that the roof sections of a building can be approximated with convex hull regions. Solidity is defined as follows [23]:

$$\boldsymbol{D_w} = \frac{\boldsymbol{S(l_w)}}{\boldsymbol{S(c_w)}} \quad \boldsymbol{D_w} \in (\boldsymbol{0}, \boldsymbol{1}]$$

where D_w denotes solidity for the watershed segmentation region, S denotes the area of the region, l_w denotes a region created by the watershed segmentation technique, and c_w denotes the convex hull which bounds l_w.

We therefore label all regions having solidity above a threshold as buildings candidate and everything below as non-buildings. For example, consider the black region in Figure 4.5 (a), its area is simply the sum of all the black pixels. The convex hull for that region is then shown in Figure 4.5 (b) in yellow and the area for that convex hull is in Figure 4.5(c) (the sum of all the yellow pixels).

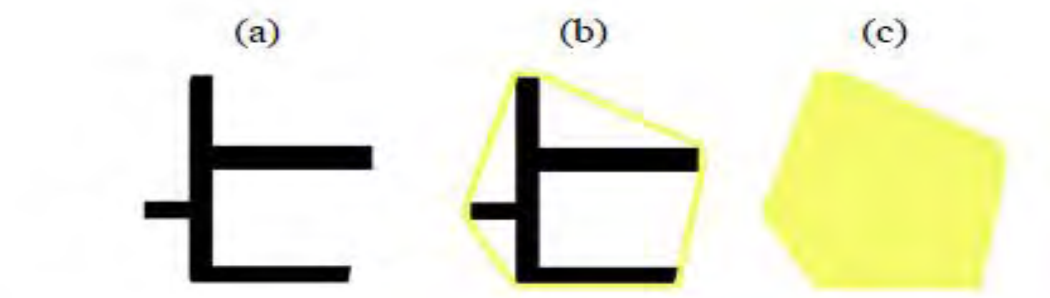

Figure 4.5: Convex Hull Example: (a) Arbitrary Region; (b) Convex Hull which Bounds the Exterior of the Arbitrary Region, (c) Area of that Convex Hull.

Finally a threshold can be used in the computed solidity value to filter building candidates. The watershed segmented image is the input and candidate buildings are the generated output. Candidate buildings are those segmented regions where their computed solidity value is above a threshold.

4.4.4 Morphological Filtering

The extracted candidate buildings in the above procedure in some instance extract large size roads and landscapes as candidate buildings. In some instances large size areas like roads and landscapes have high solidity and are extracted as building candidates. Morphological filtering is used to identify and remove such kind of objects from the candidate building map. Morphological filtering can be used to remove regions based on size and shape, by creating a structuring element and following morphological operations. The most basic morphological operations are dilation and erosion. Erosion removes pixels from object boundaries, while dilation adds pixels to the boundaries of objects in an image. A structuring element is a matrix consisting of only 0's and 1's that can have any arbitrary shape and size. The pixels with values of 1 define the neighborhood. The number of pixels added or removed from the objects in an image depends on the size and shape of the structuring element used to process the image. By creating large size structuring element and applying erosion followed by dilation operations can remove areas below the desired size and recovered large size regions. The extracted large size regions are then removed from the original candidate buildings map by subtracting it from the image.

4.5 Built-up Area Change Detection

In general change detection involves the application of multi-temporal dataset to quantitatively analyze the temporal effect. Change detection can be defined as the process of identifying the differences in the state of an object by observing it at different times. This process is usually applied to earth surface change at two or more times [5].

Built up area change detection components detect the change between a built-up map in the target reference time (2010) and initial reference time (1992). Built up area change detection component accepts the built-up maps in the two study periods and produces the change detected built up map. Change detected built up map contains buildings constructed between the target and initial reference time. Since the goal of this work is identifying informal settlements and construction between the study periods (1992-2010), these settlements are among the change detected build up areas. Building identification component discussed in Section 4.4 produces binary maps from the initial reference time and target reference time aerial photographs separately. Image differencing change detection can be used to identify the change between the two binary maps.

Image differencing change detection is relatively simple, most commonly used, straight forward, and easy to implement. It computes the image difference between the two maps and produces a map containing 0, positive and negative values. The values 0, positive and negative represent the unchanged, change from non-built-up to built-up and change from built-up to non-built up area respectively. Finally, applying the proper threshold extracts the desired changed area.

4.6 Informal Settlement Identification

Identifying informal settlement and construction is the main purpose of this work. Informal settlement and construction is building polygons which are constructed outside the permitted build up areas. So, informal settlement identification is used to identify the building polygons, which lie outside the permitted area. The labeled cadastral map and the change detected built up map are the inputs to this component. The labeled cadastral plan shows the permitted or legal built up parcels of land. On the other hand the newly change detected built up map visualizes the overall settlement areas constructed within the given time frame as discussed in Section 4.5. So, informal settlements and construction are buildings which are not officially recognized in the cadastral system.

Informal settlement identification component selects the building polygons which lie outside the permitted built up parcels in the cadastral map. Image differencing change detection is used for identification. The change detected map has a value of „0" for background and „1" for the building polygons. On the other hand labeled cadastral map has also the same value of „0" for non-built-up parcels and „1" for the build-up parcels. Image differencing change detection process enables to compute the image differencing as used in Section 4.5 to identify the building polygons which lie outside the permitted built up parcels. Since, the aerial photographs are geo-referenced and registered with the cadastral map, coordinate transformation is not needed in computing the image difference.

CHAPTER FIVE

IMPLEMENTATION

In this Chapter, we will describe the implementation details of the informal settlement and construction identification system. Data collection and preparation, development environment and the tools used to develop the system will be briefly discussed. The implementation details of the cadastral map labeling, the geo-referencing aerial photographs, building identification, built up area change detection and informal settlement and construction selection will also be described.

5.1 Data Collection and Preparation

From the view of the general scope of the work, the following datasets were identified as being necessary.

Aerial Photographs

Aerial photographs provide information on the spatial data containing the ground information of the initial reference time (1992) with a scale 1:10,000 and target reference time (2010) with a scale 1:6,000 and resolution of both images 1.5 meter, which are 4-Kilometer by 4-Kilometer sections of Woreda 10 and Woreda 11 in Yeka sub-city, Addis Ababa. They have been obtained from the Ethiopian mapping agency. These images have been geometrically corrected and geo-referenced. All the images were geometrically co-registered to each other using 8 ground control points.

Cadastral Plan

The 2010 cadastral plan of the study area is 4-Kilometer by 4-Kilometer sections of Addis Ababa is produced at scale 1:6,000 and published by Yeka sub-city Land Development and Management Office. It is parcel based land information which contains the vector map and officially approved or legal land use of each parcel of land attribute information. The land uses categories include are built-up areas, open areas, green areas, water body, river zone, and roads.

5.2 Development Tools

The implementation is done using MATLAB version 7.6.0.324 (R2008a) and ArcMap. MATLAB is a high-performance language for technical computing that integrates computation, visualization, and programming where problems and solutions are expressed in mathematical notation. Typical uses include math and computation, algorithm development; image processing, signal processing, modeling, simulation, prototyping, mapping, and the like. ArcMap is included here to create the color labeled cadastral plan into built-up and non-built-up land use category.

Developing an informal settlement and construction identification system requires a single computer resource. The computer has Intel(R) Pentium(R) Dual CPU with 2.2 GHz each processor, 2.00GB of RAM, 320GB of hard disk, and Microsoft Window 7 operating system.

5.3 Cadastral Map Labeling

Cadastral map labeling has been done in ArcMap using the vector map and the land use attribute information. The land use attribute information includes the green area, open area, river zone, water body, road and built up area. Except the built up area the other land use categories have been grouped and labeled to background with color assigned black. The built up land use has been labeled to foreground with color assigned white. The vector map and assigned color then have been combined using the parcel identification code. This has been produced a binary (black and white), which indicate white for built up area and black for the other land use categories.

5.4 Geo-referencing Aerial Photograph

Several ways can be applied to geo-reference the aerial photograph. One way is to geo-register an image by registering the image to an already geo-referenced map coordinate and creating a new "geo-referenced" image. This has been done in matlab using mapping and image processing tools. Matlab mapping tool box function "cpselect" provides an interface tool for control point selection as shown in Figure 5.1. The interface contains the input layer and the Base layer and selection tool. First, the input image (aerial photograph) and base map (labeled cadastral map) have been read and displayed in the input and base layers, respectively, in the control point selection tool. Reading the labeled cadastral map is done by matlab mapping tool box function „geotiffread ( )‟. After reading and displaying the geo-referencing process, the system performs the registration of aerial photo to base map labeled cadastral map coordinate and applies the geometric transformation. The image registration and geometric transformation are discussed below.

5.4.1 Register Aerial Photograph to Map Coordinates

This step enables geo-registration based on control point pairs and exports the control point structure to work space. The control point pairs have been related to each other using the “add points” tool in the control point selection tool. Control points have been obtained by ground survey. In labeled cadastral map marking control points have been done in arcMap prior to exporting the cadastral map. The selected control points are saved using a structure array and exported to the work space using the “Export points to workspace” submenu in the “File” menu.

5.4.2 Geometric Transformation

This step extracts the control point structure from the structure array and performs the following activities to geometrically transform the registered image in the base map and produce a geo-reference matrix for the registered image. “cpstruct2pairs” is the matlab function used to extract the control points from the control point structure. Map scale variations are also resampled in this step. Geometric transformation algorithm includes several tools from mapping and image processing toolbox in Matlab. First, predicting the corner location of the registered image, calculating the average pixel size of the input image (in map units) and finding the centers of the upper left and lower right corner pixels have been done using Matlab Image and Mapping toolbox functions. Bounding box for the registered image has been displayed by computing the floor and ceil of the corner locations in all directions and connecting to each other using the function „line ( )‟. Transformation of the aerial image to an image that should fit just right within the output bounding box has been done by transforming the input aerial photographs with the parameter of the corner location of the registered image, corner pixel centers and pixel size. The Matlab image processing tool box function „imtransform ( )‟ is used to transform the given image based on the given parameters.

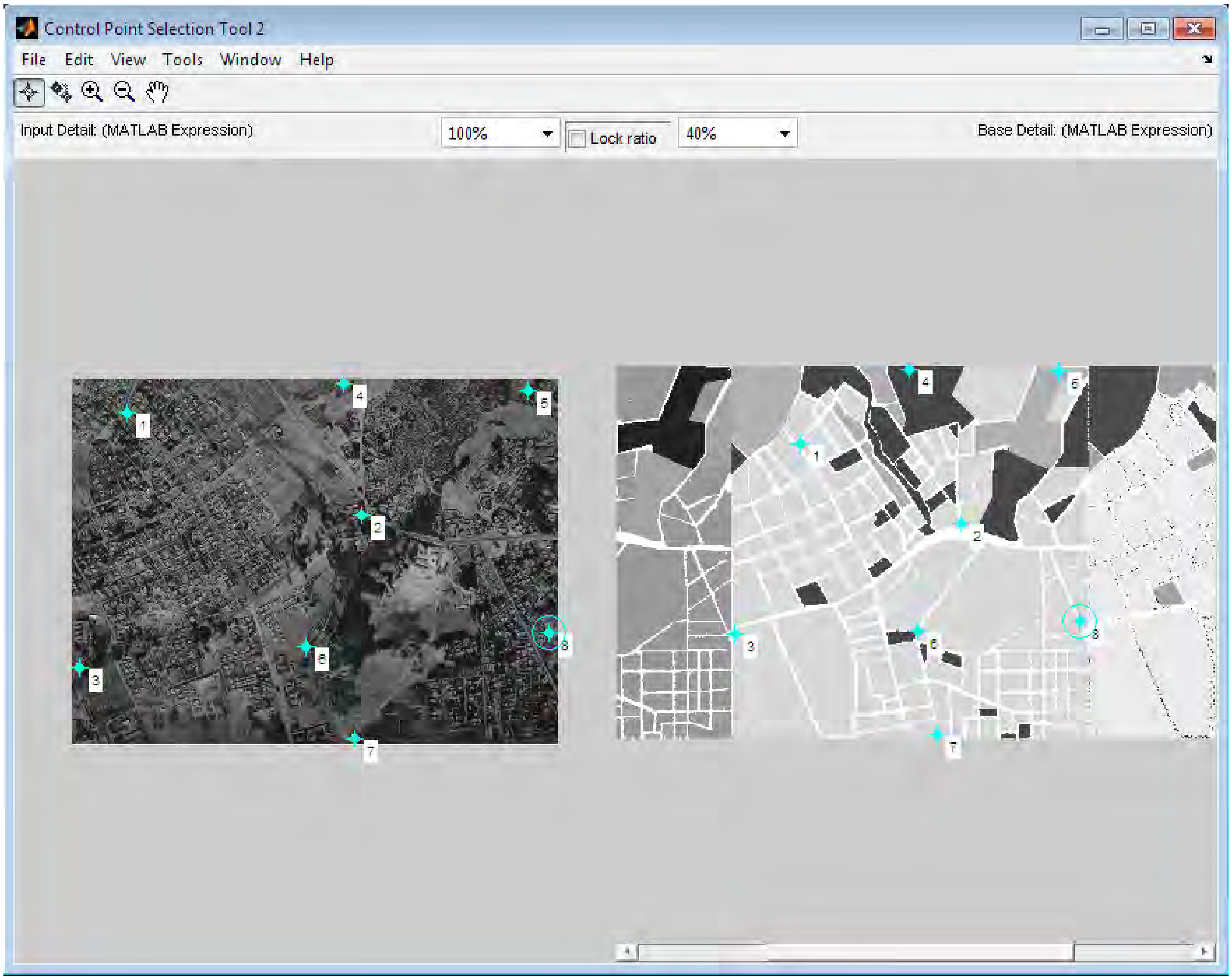

Figure 5.1: Control Point Selection Tool

5.5 Buildings Identification

Aerial photograph contains all the geo-spatial data on ground from the top point of view. To identify the informal settlements and construction from aerial photographs it is necessary to single out buildings. Our methodology of building identification was according to more general assumptions, which are buildings tend to have convex hull rooftop sections as discussed in Section 4.4. To detect buildings, the image has been segmented using watershed segmentation and the solidity of each region was computed to filter more convex hull objects, i.e., candidate buildings. Large size landscapes and roads have been also identified and removed from the candidate build-up area. This component accepts the geo-referenced and registered aerial photograph and produces a binary map which indicates „1‟for built up area and „0‟ for non-built up area.

5.5.1 Image Pre-processing

Image pre-processing of the aerial photograph is used to increase both the accuracy and the interpretability of the digital map during the building identification phase. Noise removal have been done using wiener filter, it is 2-D adaptive noise-removal filtering. Wiener filter estimates the local mean and variance around each pixel, with the N-by-M local neighborhood of each pixel. The Matlab function "weiner2" is used to implement the wiener filter.

5.5.2 Image Segmentation

Buildings and non-buildings are detected by measuring the solidity of their regions. The regions are obtained by image segmentation using watershed segmentation. Watershed segmentation incorporates filtering input image using gradient filter, threshold gradient filter image, distance transformation and watershed transform.

a. Image Filtration using Gradient and Threshold Gradient Filtered Image

To segment the image it is necessary to identify the boundary of each region. Gradient filtration and threshold gradient filter image are used to find the boundary of individual regions. To extract these pixels, the image has been texturally filtered.

Gradient filtration such as entropy filter first reads the input image and filtered the image using gradient. „entropfilt‟ function in Matlab has been used to produce the gradient filter image. A threshold value 0.7 was appropriate in order for extraction of high gradient areas, which are border pixels. It is selected by training process. Figures 5.3 and 5.4 show the gradient filtered image and the thresholded image of gradient filter image of the input image in Figure 5.2, respectively.

Figure 5.2: Sample Input Image

Figure 5.3: Gradient Filtered Image

Figure 5.4: Thresholded Gradient Filter Image

b. Distance Transform

Distance transform is used to mark the foreground objects by calculating the distance between each pixel that is set to off (0) and the nearest nonzero pixels for binary images. The Matlab function "bwdist ( )" calculates the distance transform of a given binary image. Figure 5.5 shows the distance transform image of the binary image shown in Figure 5.4.

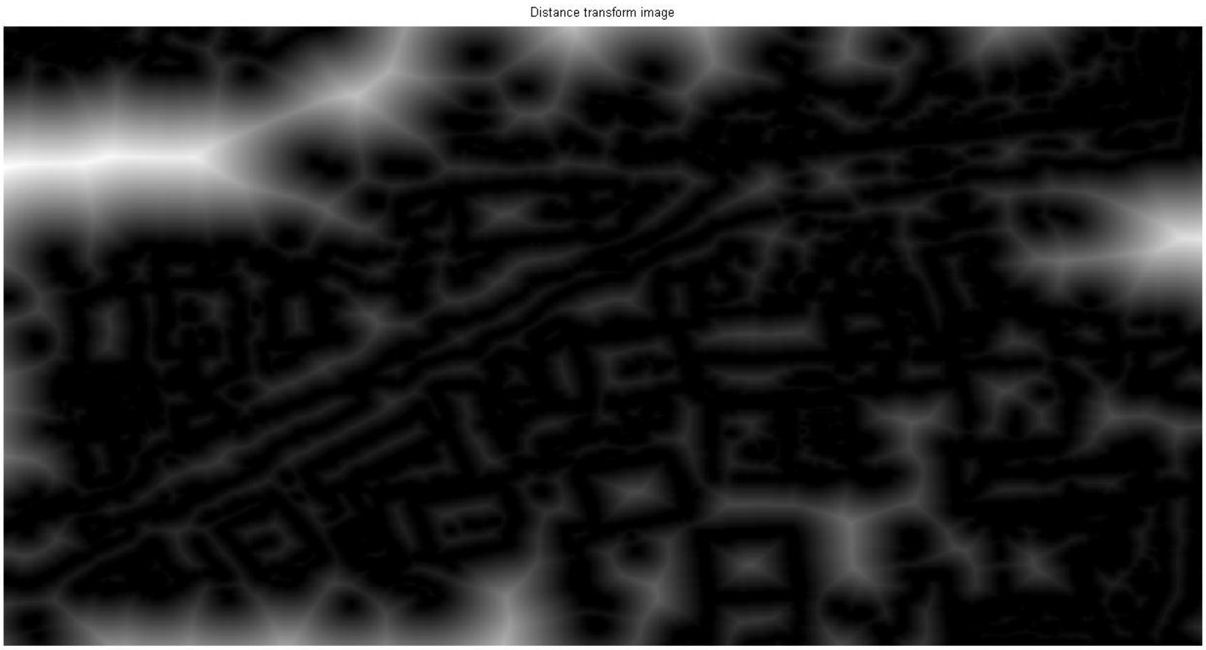

Figure 5.5: Distance Transform Image

c. Watershed Transform

To find individual color label regions, watershed transform has been used. The watershed transform finds "catchment basins" and "watershed ridge lines" in an image by treating it as a surface where light pixels are high and dark pixels are low. The first step in watershed transform is finding catchment basins and watershed ridge lines. In the distance transform image which is computed before. Light pixels and dark pixels are indicators of catchment basins and the watershed ridged lines respectively. In Matlab, the function “watershed ( )” computes a label matrix identifying the watershed regions of the input distance transform image as shown in Figure 5.6.

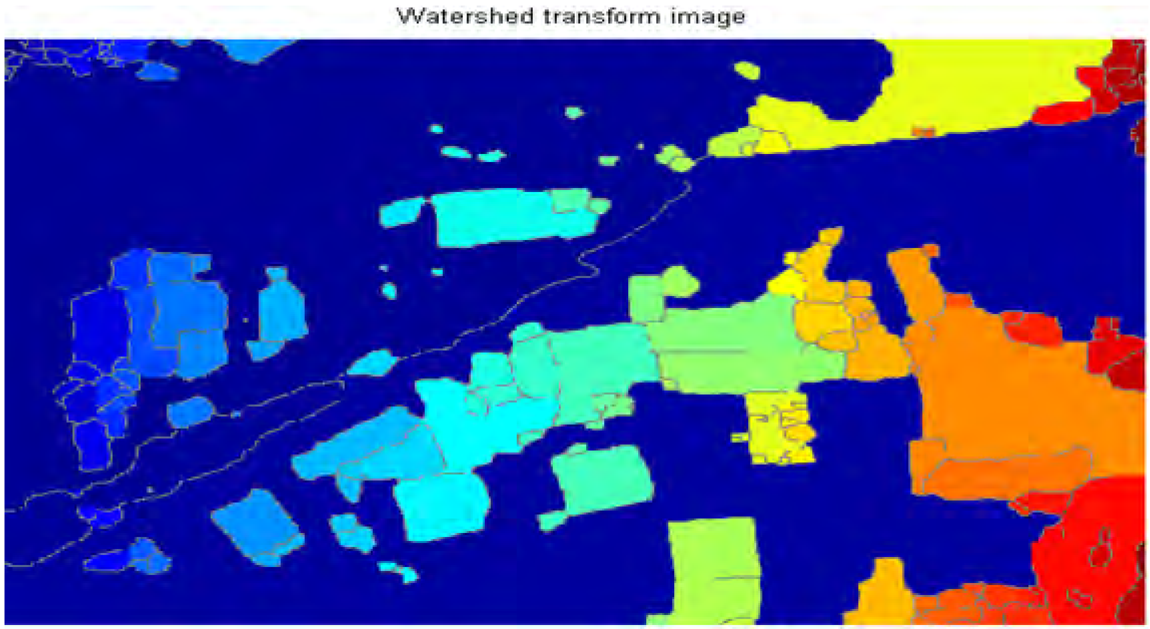

Figure 5.6: Watershed Segmented Images

5.5.3 Solidity Measurement and Candidates Building Extraction

Buildings have high solidity. To filter buildings from other objects in the image it is necessary to measure the solidity of each region. The solidity measurement and candidate building extraction algorithm selects individual regions and computes the area of the region and its convex hull. Finally, the solidity of the region is obtained by computing ratio of the area to the convex hull. In Matlab, the function "ismember ( )" is useful in conjunction with "regionprops ( )" for selecting regions based on certain criteria. The function "regionprops ( )" with the parameter "Solidity" has been used to compute the ratio of area of the region over its convex area for 2-D input label matrices. The function "ismember ( )" is also used to extract desired regions based on the threshold value parameter. The threshold 0.7 was appropriate in the extraction of candidate buildings as shown in Figure 5.7.

Figure 5.7: Candidate Buildings

5.5.4 Morphological Filtering

Candidate buildings produced in section 5.5.3 in the above procedure sometimes extract large size roads and landscapes as candidate buildings as discussed in Section 4.4.4. Large size regions have been removed by morphological filtering. Morphological filtering have been applied by creating a 11 by 11 structuring element using the Matlab function "strel ( )" and erodes the image three times using the function " imerode ( )". This removes all buildings and others which don"t have large size and extract small portion of large regions. The morphological operation dilation using the function "imdilate ( )" with the same structuring element three times as done in erosion recovers the remaining regions of large size regions into their original size. This is then subtracted from the original candidate building map. The output image is the final building map.

5.6 Built-up Areas Change Detection

To identify the informal settlement and construction first the buildings constructed in a given time frame should be identified. Build up area change detection algorithm is used to identify the buildings constructed in the study area between 1992 and 2010. This algorithm reads the two classified images in Section 5.4 and computes the image difference between the two maps. For building identification in Section 5.4, the aerial photographs of the 1992 and 2010 have been classified in to build up areas and background region. Image difference between the late study period (2010) and early (1992) and the selected threshold „1" extracted the built-up area change detected map. Matlab image processing tool box function „imsubtract (im1,im2)" is used to compute the image difference. The two classified images in early and late study periods were in the same spatial coordinate system, so that there was no need of coordinate transformation for computing the image difference.

5.7 Informal Settlement Identification

Informal settlement identification algorithm is used to identify the building polygons, which lie outside the permitted build up areas. It computes the change between the changes detected build up map and the labeled cadastral map. Since the two maps are binary maps, informal settlement identification has been done using change detection between the two maps by computing the image difference and applying the threshold of "1" for informal and „0" for formal settlements area extraction on the difference image. These extracted areas are buildings which lie outside the permitted build up parcels, i.e., informal settlements and construction.

5.8 The Prototype User Interface

Based on the designed model, the prototype system is developed to evaluate the performance of the proposed model. Figure 5.9 shows the informal settlement and construction identification system.

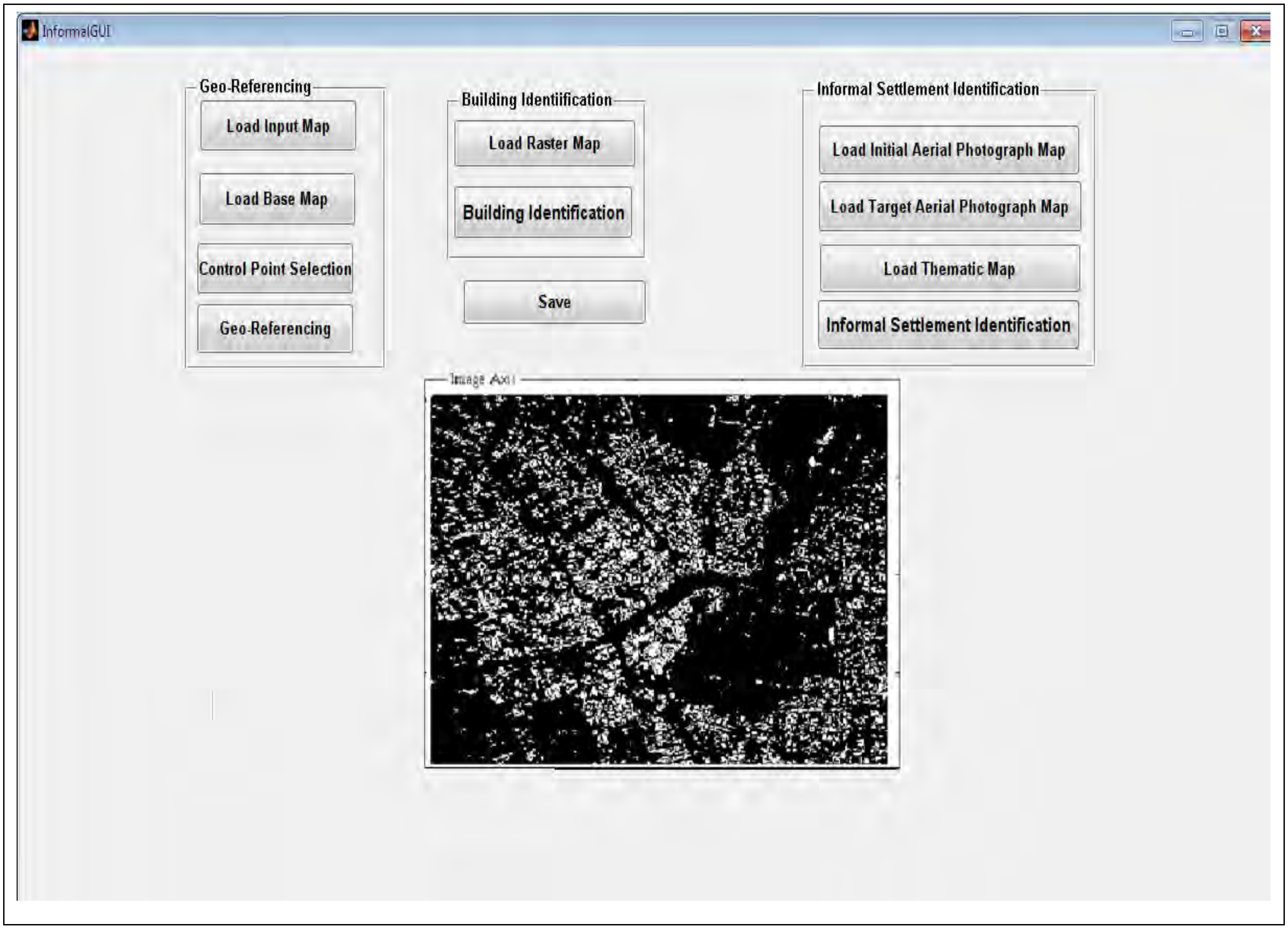

Figure 5.8: Sample Prototype for Informal Settlement and Building Construction Identification System

To use the prototype system, the input aerial photographs are geo-reference in "Geo-referencing" group by reading the aerial photograph using "Load Input Map" and the geo-referenced map is used as a base map using "Load Base Map" buttons. After loading the maps, we will press the "Control Points Selection" button to register the input image, and then the button returns the control point selection tool provided by Matlab image processing toolbox as seen in figure 5.1. "Geo-referencing" button applies a geometric transformation and creates reference matrix for the registered image as discussed in Section 5.3. The output map is saved in selected locations with the file format using "Save" button.

The input raster maps which are the geo-referenced aerial maps in the initial and target reference time are read in the “Building Identification” group using the “Load Raster Map”. After the initial reference time map is loaded the buildings are identified using the “Buildings Identification” button. The output is then saved in the selected location. Informal settlement identification is done from “Informal settlement identification” group by reading the geo-referenced aerial photographs of the initial and target reference times using “Load Initial aerial photograph Map” and “Load Target Aerial Map” buttons respectively. The labeled cadastral map is also loaded from the stored location using “Load Thematic Map” button, and then pressing “Informal settlement identification” button. Informal settlement identification group incorporates the building identification, change detection and informal settlement selection components.

5.9 Summary

The informal settlement and construction prototype system which is developed in this research work has four main components which are interconnected with each other to extract informal settlement and construction from the input aerial photograph. The geo-referencing component is used to make all the images in the same spatial location. The building identification components classifies the geo-referenced maps in the initial and target reference times into built-up and non-built up areas by following image processing formats image pre-processing, image segmentation and building identification. The change detection component computes the change between build up maps identified and stored in the building identification components. The informal settlement identification component selects building polygons from the change detected built up map which lies outside the permitted settlement area using change detection between the labeled cadastral map and the change detected built up map. The different algorithms and sub-components under the four main components are also presented.

CHAPTER SIX

EXPERIMENT AND EVALUTATION

6.1 Built-up Area Map

The system discovered that the built-up area in the two different times showed significant changes. Built up area coverage was drastically changed from **11.83%** in 1992 to 42.55% in 2010. Built up area grew 30.72% in 18 years and it was around 1.7% per year (Table 6.1). Non-built-up area, which constituted 88.17% of the total area in 1992, diminished to 57.45% in 2010. The built up areas including continuous and discontinuous urban fabrics, industrial, commercial and residential units with other associated urban facilities dynamically increased in the period under discussion. This might be due to high acceleration of population increment with high demand for land and urban provisions, land allocation policy of the government, informal settlement, and unplanned (slum) urban sprawl at the periphery of the urban area.

Built-up areas in our work comprise industries, enterprises, commercial, residential, construction sites, sport and leisure facilities etc. Non-built-up areas include roads, agricultural lands, open fields, natural and man-made forests, natural grasslands, water body and others.

As the main theme of this study was to investigate the informal settlements thus, more attention was given to analyze the extent of built-up areas in comparison with other land cover classes. Thus, in order to examine the nature and spatial extent of the built-up areas, the input maps (Figures 6.1 and 6.2) were classified into two broad classes as built up and non-built-up areas (Figures 6.3 and 6.4 respectively). This graphic presentation enables a direct comparison of settlement changes in different time limits.

Figure 6.1: Aerial Photograph of the Study Area (1992)

Figure 6.2: Aerial Photograph of the Study Area (2010)

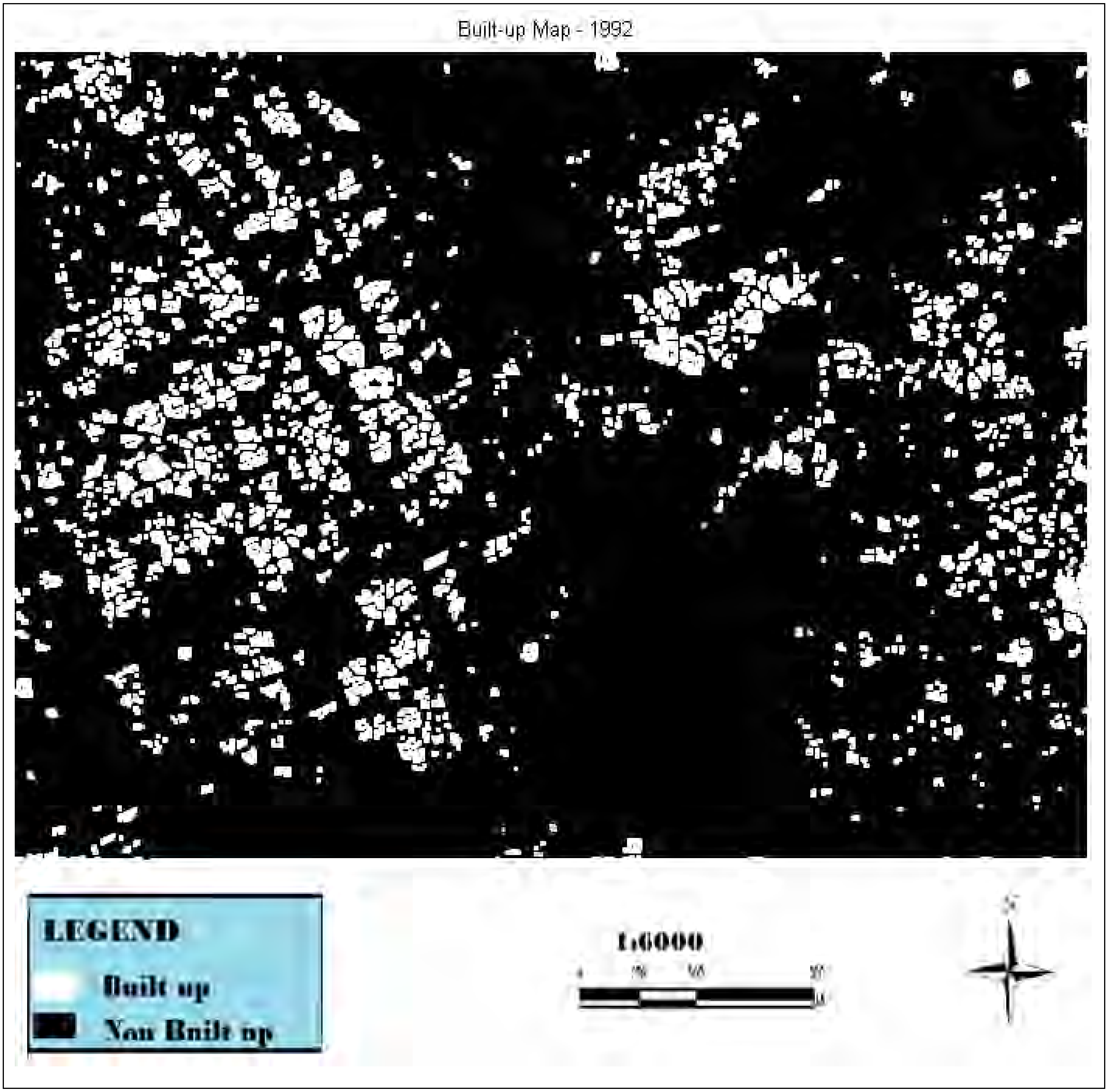

Figure 6.3: Built up Area Map of the Study Area (1992)

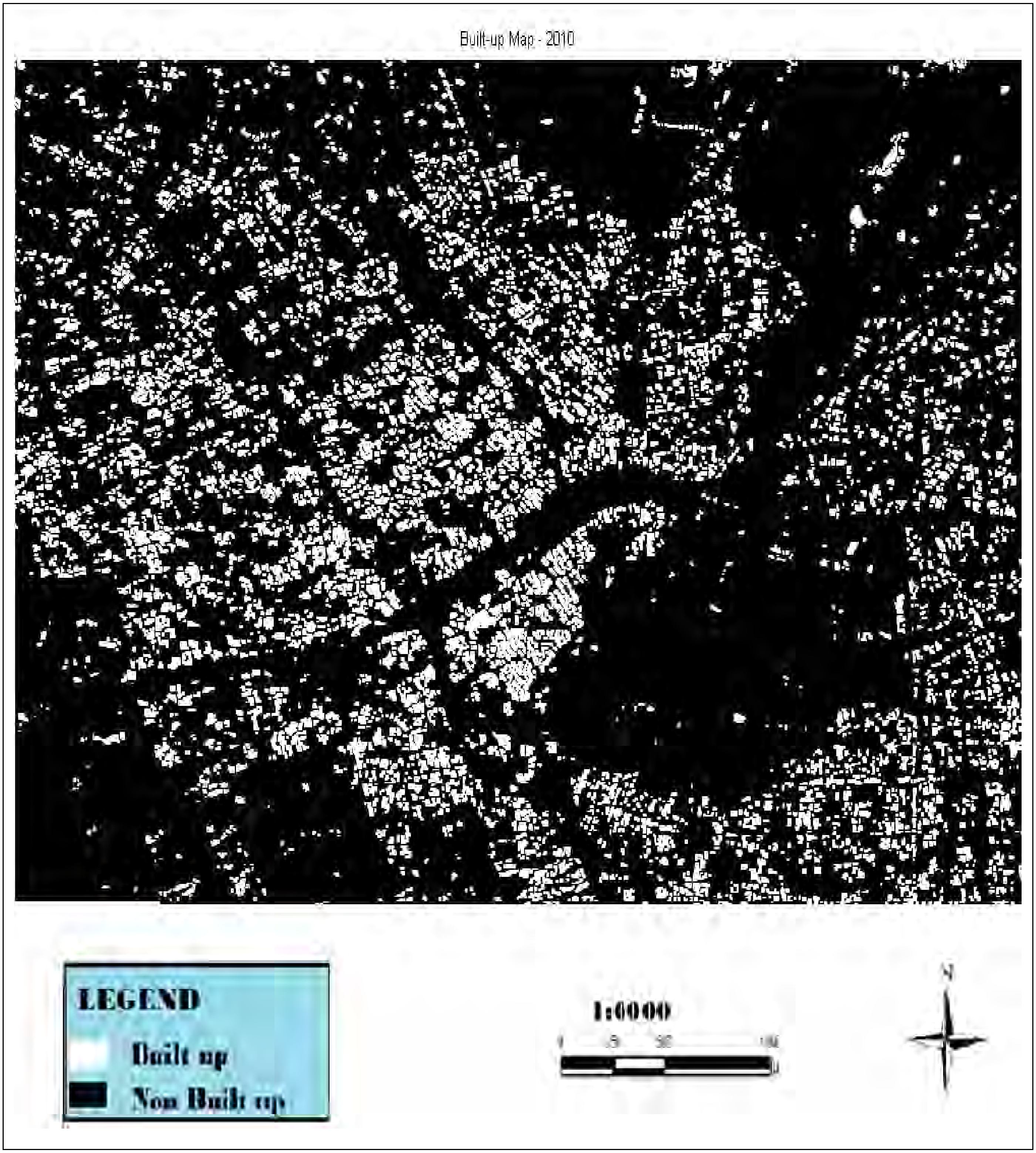

Figure 6.4: Built up Area Map of the Study Area (2010)

The rapid population increase of the study area has been mainly attributable to natural urban population increase and internal migration. According to the country‟s 1994 population and housing census, out of the total population of the city, 46.7% were migrants from rural and other urban areas in Ethiopia [20]. Thus, the population increment requires additional space for settlement and construction.

6.2 Change Detected Built-up Map (1992-2010)

The change detection analysis can be employed using two multi-temporal images of the same site but in different time periods. Different techniques, for example, image differencing, image regression and image rationing can be mentioned as techniques for change detections. The selection of an appropriate technique, however, depends on the knowledge of the algorithms and characteristic features of the study area [31].

In this study, the most straightforward technique for detecting changes (comparison of independently produced build-up area maps from two dates) has been applied. The maps of 1992 and 2010 which are considered as “initial image” and “target image”, respectively were overlaid up on each other and analyzed. Both images were initially classified into two different thematic classes (Figures 6.3 and 6.4). The difference between the two maps enabled us to find the settlement change map (Figure 6.5).

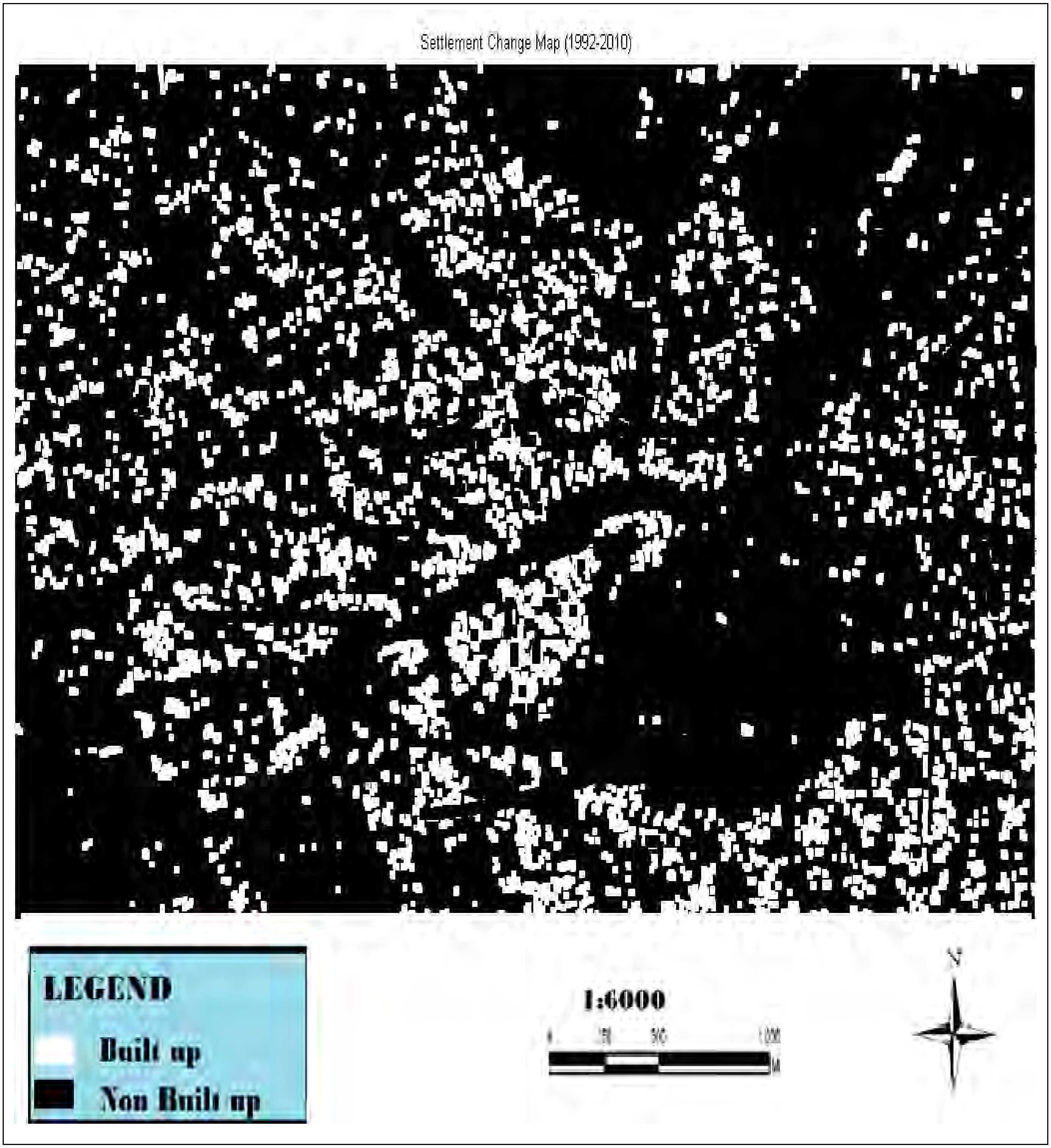

Figure 6.5: Built-up Area Change Detected Map of the Study Area (1992-2010)

Addis Ababa is the capital and metropolis of the country with around 3.8 million people, with high demand for commercial, industrial, residential and recreational lands uses. Thus, the dominant land use class is an urban (built-up) and associated area. It occupies the highest proportion of the study area. The build-up maps derived from remote sensing data also present the changes from non-built to built-up areas. Preliminary results from the multi-date visual change detection image indicate that a considerable urban built-up area change took place in the study areas. As depicted in Table 6.1, the built up class has experienced a remarkable growth (149150 M^2) between 1992 and 2010.

Table 6.1: Built-up and Non Built-up Areas and Changes between 1992 and 2010

Land Cover	**1992**		**2010**		**1992-2010**	
	Area (M^2)	*Area (%)*	*Area (M^2)*	*Area (%)*	*Change(M^2)*	*Change (%)*
Built up	1892823.66	11.83%	6808085.1	42.55%	4915261.44	30.72
Non Built up	14107376.34	88.17%	9192114.9	57.45%	-4915261.44	30.72
Total	16000200	100%	16000200	100%	-	-

6.3 Informal Settlement and Building Construction Map

The informal settlement identification can be employed using the labeled cadastral map of the study area (Figure 6.6) and the newly identified settlement map of the study area (Figure 6.5). The change detected map is compared with the labeled cadastral map of the study area. The building polygons that lie outside the permitted settlement areas are informal and settlements laid inside the permitted settlements are formal settlements. This is implemented by computing the image difference of the change detected map and the labeled cadastral map. Figure 6.7 shows the identified informal settlement map of the study area.

Figure 6.6: Labeled Cadastral Map of the Study Area (2010)

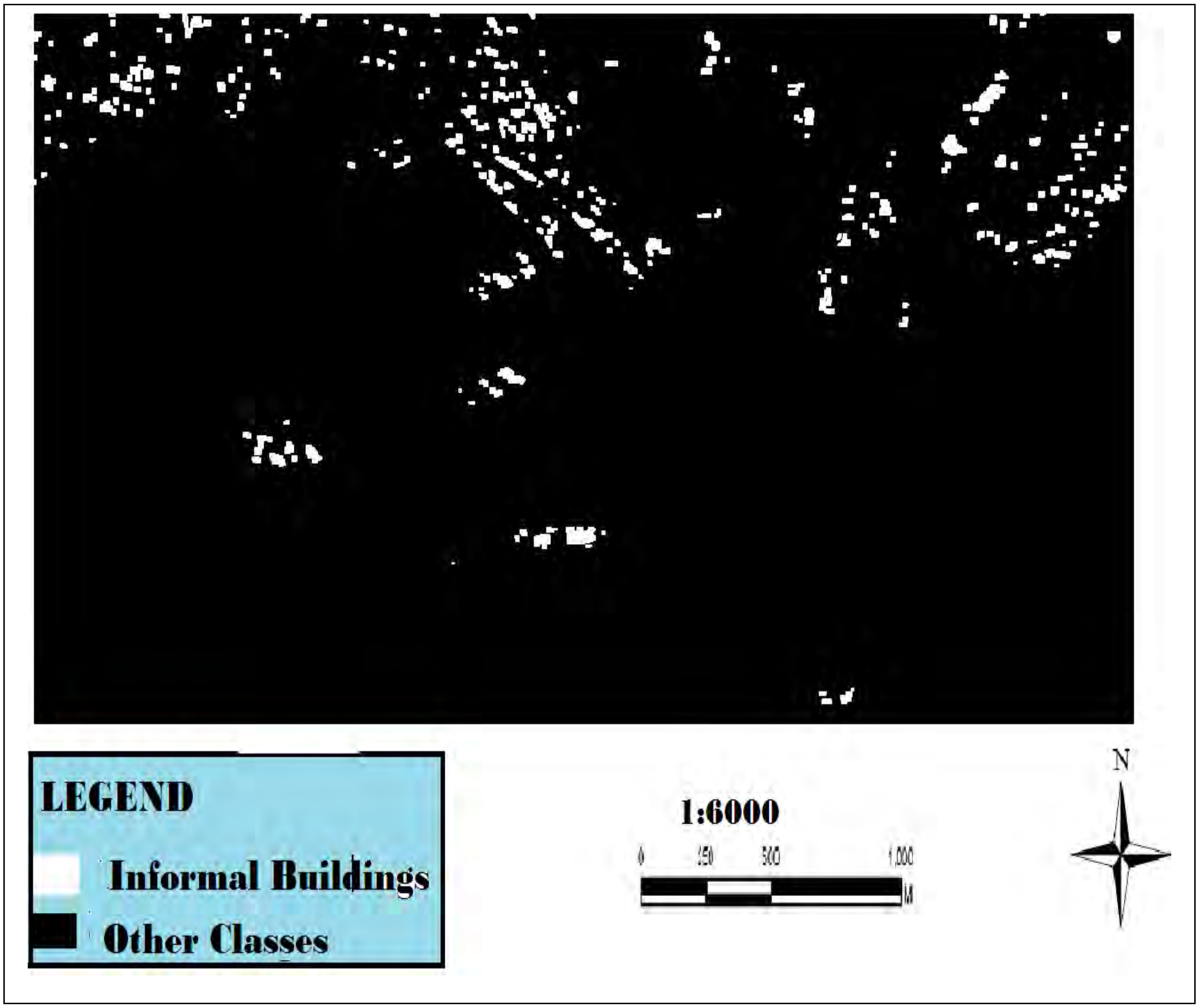

Figure 6.7: Informal Built up Area Map

The results from the classified image indicate that considerable informal settlements are found in the study areas as depicted in Table 6.2. From the settlement change detected results 28.9% are informal settlements with annual growth rate of around 1.61%. Most of the settlements occurred in the peripheries of the study area.

Table 6.2: Informal and Formal Built up Areas in the Selected Area

Built up areas Changed	Area (M^2)	Area (%)
Informal (1992-2010)	1420510.56	28.9 %
Formal (1992-2010)	3494750.88	71.1 %
Total	4915261.44	100%

6.4 Accuracy Assessment of Building Identification

Assessment of classification accuracy is critical for a map generated from any remote sensing data. Although accuracy assessment is important for traditional remote sensing techniques, with the advent of more advanced digital satellite remote sensing, the necessity of performing an accuracy assessment has received new interest [30]. Currently, accuracy assessment is considered as an integral part of any image classification. This is because image classification using different classification methods or algorithms may classify or assign some pixels or group of pixels to wrong classes. In order to wisely use the settlement maps which are derived from remote sensing images, the errors must be quantitatively explained in terms of classification accuracy.

Classification accuracy provides an overall result for the error matrix. Manually classified image from the cropped aerial photographs of early and late period were used as a reference map in the accuracy assessment of the classification system Table 6.3 and Table 6.4 show confusion matrices of aerial photograph of 1992 and 2010 respectively.

Table 6.3: Confusion Matrix for Sections of Aerial Photograph of 1992.

		System Classified Map			
		Built up (M^2)	Non Built up (M^2)	Grand Total (M^2)	Producers accuracy
Reference map	Built up (M^2)	79578	48727	96753	82.2%
	Non Built up (M^2)	11939	253691	297182	87.4%
	Grand Total (M^2)	91517	302418	393935	--
	User‟s accuracy	86.9%	83.9%		

Table 6.4: Confusion Matrix for sections of Aerial photograph of 2010.

		System Classified Map			
		Built up (M^2)	Non Built up (M^2)	Grand Total ((M^2)	Producers accuracy
Reference Map	Built up (M^2)	82628	18711	101339	81.5%
	Non Built up (M^2)	12834	278330	291164	85.5%
	Grand Total (M^2)	95462	297041	392503	
	User‟s accuracy	84.5%	87.7 %		

a. Overall Accuracy of Building Identification

This provides an overall result for the confusion matrix. The overall accuracies for the building identification map of the study area in 1992 and 2010 were 84.9% and 85.2%, respectively. It is computed by dividing the total correctly classified number of pixels (i.e. summation of the diagonal) to the total number of pixels in the matrix (grand total), of Table 6.3 and 6.4 respectively. For example the overall accuracy (acc) of 1992 map in Table 6.3 are computed by as follows:

acc= summation of correctly classified pixels/total number of pixels

acc= (79578 + 253691)/ 392503

acc=84.9%

b. Producer's Accuracy

Producer accuracy was obtained by dividing the number of correctly classified pixels in the category (79578 and 253691 in the first and second raw respectively of table 6.3) by the total number of pixels of the category in the reference data (96753 and 297182 in the first and second raw respectively of table 6.3). Producer‟s accuracy is sometimes termed as an Omission Error, which is the probability of reference pixels being classified correctly. This accuracy only gives the proportion of the correctly classified pixels. The result of this work revealed that the value of producer‟s accuracy in 1992 map ranged from the lowest 82.2% to the highest 87.4%, while in 2010 map it ranged from 81.5 % to 85.5% (see Tables 6.3 and 6.4). For instance, the producer‟s accuracy 82.2% in 1992 map indicates that 82.2% of the total built up area in the reference map is correctly identified as built up area in the systems classified map.

c. User's Accuracy

User‟s accuracy was obtained by dividing the total number of correctly classified pixels category (79578 and 253691 in the first and second raw respectively of table 6.3) by the total number of pixels on the classified image (95462 and 297041 in the first and second raw respectively of table 6.3). This method explains the probability that the pixel‟s in the classified map or image represent that class on the ground. User‟s accuracy of individual classes ranged from 86.9% to 83.9% for 1992 map and 84.5% to 87.7% for 2010 (see Tables 6.3 and 6.4).

6.5 Evaluation of Informal Settlements and Construction Identification System

The accuracy assessment of the whole system was carried out by comparing the manually identified informal settlements and building construction with the identified informal settlements and building construction from the system. Manually identified informal settlements and construction are obtained using cropped aerial photographs of the early and late reference time and section of cadastral map of the cropped image. The confusion matrix of the identification system is shown in Table 6.5

Table 6. 5: Confusion Matrix of Informal Settlement and construction identification

		Identified Informal Settlement and Construction Map			
Reference map		Built up (M^2)	Non Built up (M^2)	Grand Total (M^2)	Producer‟s accuracy (%)
	Built up (M^2)	5255	1391	6646	79.1%
	Non Built up (M^2)	1203	34721	35924	96.6 %
	Grand Total (M^2)	6458	36112	42570	
	User‟s accuracy (%)	81.4%	96.1 %		

The results found are due to the errors that were encountered during the study. The errors were Geo-referencing errors, and errors in building identification from aerial photographs. Much of the errors are occurred in building identification from aerial photographs as discussed in accuracy assessment of building identification (Section 6.3).

The overall accuracies for the informal settlement and construction identification map of the study area were 93.9 %. It is computed by dividing the total correctly classified number of pixels to the total number of pixels in the matrix (grand total). Producer‟s accuracy map ranged from the lowest 79.1% to the highest 96.6%, and user‟s accuracy ranged from 81.4% to 96.1% (see Table 6.5).

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATION

7.1 Conclusion

Informal settlement over time is the response of combined effect of the social, economic, demographic and environmental variables. Understanding the characteristics, the extent and the pattern of informal settlement is a vital element for efficient planning, managing and decision making activities. In the absence of basic information about the current settlement areas, it would be difficult to determine future improvements. This leads to suggest the need to provide up-to-date information about land-related resources to help planners in decision-making. Based on the results achieved and analysis done, it is concluded that the objectives of the work were adequately achieved. The following conclusions were deduced from the study.

Integrated approaches of cadastral map and remote sensing and image processing are excellent tools to map informal settlement in different spatio-temporal scales and to quantify the extent and pattern of these settlements. The availability of high resolution remote sensing data, image processing along with GIS have been providing an opportunity to generate settlement map of certain geographical area, to observe different changes in different time and modeling the future characteristics.

As already mentioned on the design part, different image processing techniques and different procedures were employed to identify the informal settlement area in the selected region and quantify their extent for the case 1992 to 2010 of the study area in Addis Ababa, Ethiopia. This would also play an important role in understanding the nature, where informal settlements were occurring, projecting possible future change and planning future urban development.

This study has demonstrated the role of multi-temporal aerial photographs and cadastral map in producing informal settlements maps in case of indigenous city structure, section of Addis Ababa for the 18 years between 1992 and 2010. In the study area, similar study has not been carried out to quantify and detects informal settlements.

The study shows that settlement between two different times showed significant area of informal settlement. Urban coverage was drastically changed to built-up area from 11.83% in 1992 to ***42.55%*** in 2010. From **491526.44** sq. meter built up areas between 1992-2010, **1420510.56** sq.

meter are informal built up area, which is 28.9% with annual growth rate of 1.61 %. Most of the informal settlements occurred in the peripheries of the city.

7.2 Contributions of the Work

The main contributions of this research work are given below.

- Identify the major components of informal settlement and construction identification that should be considered in the development of informal settlement and construction identification.
- Identify the critical issues that need to be dealt in informal settlement and construction identification and proposed appropriate techniques.
- Design the general architecture of automatic informal settlement and construction identification using image processing of high resolution aerial photographs and change detection with the cadastral map.
- Developed algorithm for geo-referencing aerial photograph, automatic building identification from high resolution aerial photograph and automatic informal settlement identification.

7.3 Recommendations

Full coverage and up-to- date informal settlement and construction identification system needs an up-to-date high resolution and high budget for data collection and coordinated team of. Additional features, improvements, and modifications should be incorporated to come up with an effective and efficient informal settlement and construction identification. Hence, we propose the following recommendations for future research direction.

- The developed techniques in building identification can be improved for better accuracy. If a single building exists as an "L" shape and has a single section across its entire roof, then this approach would most likely erroneously classify such a building as non-building. Additional techniques that solve this limitation can be developed to give the more efficient building identification technique.
- The proposed technique identifies informal building construction. However, informal construction includes parcel fences and other constructions. Additional techniques

factoring informal constructed parcel fences can be developed to give the more efficient informal settlement and construction identification system.

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Declaration

I, Undersigned, declare that this thesis is my original work and has not been presented for degree in any other university, and that all sources of material used for the thesis have been acknowledged.

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