Natural Urban Process Modeling with Applications to the City of Bergen

Master Thesis in Software Engineering

by

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March 2019

Abstract

It is vitally important to understand the relationship between the urbanity level and the design of a city, and to determine the factors that make cities live better when connected to each other in a good way. City design is considered as the key feature that influences people activities within the spaces of their city, and it increases or decreases the interaction between citizens and these spaces. City spaces are understood through symbols and signs that are manifested through buildings, streets, and squares that make up the identity of any city. Usually, this identity is described by the image that people have in their minds about their city. A city is more than buildings and people living or working inside these buildings. A city is a state of mind, a body of customs, traditions, feelings, attitudes and the collective activities of its residents. A city is a product of nature, especially of human being nature.

In this thesis we show how to compute metrics that indicate the urbanity level of any city using the space syntax theory in combination with geographic information systems, and investigate the relationship between the metrics and some problems related to sustainability, such as the relationship between the street network design and energy consumption of cars.

Contents

Chapter 1

Introduction

“We shape our buildings, afterwards, our buildings shape us”.
Winston Churchill.

Spaces inside a city have a value. This value is defined by the city buildings and streets that form the city. The syntax of words refers to the relationship between the words of the sentence. It is the system by which we arrange words to let the sentence get a specific meaning. In the same way, spaces inside a city can be arranged or designed in a way that makes sense to the people who live in or visit the city. Good design leads to a more social city and encourage people to walk more inside it. The buildings, streets and spaces of a city also impact the sustainability of the city, for example, in terms of energy used to transportation.

This logic of space represents spaces as networks composed of certain spatial elements. These networks have configurations depending on the depth of a spatial element in relation to other spatial elements in the city. The space syntax theory [10] has made the logic embedded in an existing spatial organization clear and understandable. In view of the fact that cities are models which allow changes over time, the goal of this thesis is to enable the analysis of the urban design process and setting clear strategies to support and enhance urban growth in cities in the future.

1.1 The Spatial Modelling Method

The most significant idea of space syntax is that the configuration of a space is more important than the space itself, it gives a wider understanding of how cities operate. The space syntax theory is used as a method for describing and analyzing the relationship between spaces of urban areas and the buildings. In the space syntax theory, spaces are understood as voids such as streets, squares, rooms and fields, between walls, fences and other things that restrain pedestrian movement or the visual field. The idea assumes that most people, most of the time, will take the simplest route to their destination. That route tends to involve the fewest changes of direction. The more changes of direction, the more complex the system, and therefore the more ineffective or inefficient the network design becomes.

Movement in cities is generated by the configuration of the cities’ streets. This fundamental relationship underlies many aspects of cities including the distribution of land use and the spatial patterning of crime for example. Space syntax research has shown that ineffective configuration in cities or housing estates can cause social segregation and antisocial behavior. Such examples have given rise to the notion of good, or bad, syntax. To better illustrate this point, Hillier provides an analogy between architecture and language:

“Language is often naively conceptualized as a set of words and meanings, set out in a dictionary, and syntactic rules by which they may be combined into meaningful sentences, set out in grammars. This is not what language is, and the laws that govern language are not of this kind. This can be seen from the simple fact that if we take the words of the dictionary and combine them in

grammatically correct sentences, virtually all are utterly meaningless and do not count as legitimate sentences." (Hillier 1996, pp 7), [10].

Similarly, successful city architecture is not just about simply constructing streets and connecting buildings, and neighborhoods, it is also about how different parts of the city are connected all together.

The design process has a key role to play in making new towns and cities more efficient and more effective places to support human life in all of its activities: living, working, visiting, creating, innovating, and celebrating. Design concerns not only the visible elements of the city: the buildings and urban spaces through which people move and interact, but also the invisible city: the tunnels, pipes, cables and digital networks that support urban life.

In the spatial modelling method [7], the three components: space syntax, spacematrix, and mixed-use index (MXI), are used to assess street-network integration, building density, and land-use mixture of the city. These three elements are then incorporated into a single framework. Based on this framework, we can determine the relationship between the city design and any kind of phenomena or events that happen in the city, like the crime rates or the robberies that take place always in one part of the city but not in the other parts. The method helps to reveal the interdependences of street-network integration, building density, and land-use mixture in urban transformation processes.

GIS (Geographic Information System), which will be used as the underlying computation platform in this thesis, refers to a number of different technologies, processes, and methods. GIS is attached to many operations and has many applications related to engineering, planning, management, transport/logistics, insurance, telecommunications, and business. For that reason, GIS and location intelligent applications constitute the foundation for many location-enabled services that rely on analysis and visualization.

GIS can relate unrelated information by using location as the key index variable. Locations or extents in the earth space-time [21] dimensions may be recorded as dates/times of occurrence, and x, y, and z coordinates representing, longitude, latitude, and elevation, respectively. All earth-based spatial-temporal location and extent references should be relatable to one another and ultimately to a "real" physical location or extent.

This key characteristic of GIS has begun to open new avenues of scientific inquiry. For instance, in the health sector, GIS systems are used for tracking occurrences of diseases. And one of GIS most powerful aspects is its ability to use geography to identify where diseases are most likely to spread next. Data such as this can be essential to on-the-ground personnel working to save lives, as it enables them to be prepared in advance for a disease and can thereby limit the impact.

GIS started to play a significant role in the management of disease outbreaks such as Ebola and measles. For instance, in December 2014 [22], during the Disneyland measles outbreak, GIS-based maps were created to help visualize where infected children lived and the potential spread of the disease. Another example of using GIS in the health sector is what happened during the 2012-2013 flu season, where researchers queried Twitter for tweets indicating sickness. They used terms such as 'flu' 'influenza' and 'medication' and geographically located where the tweets were sent from. By adding this data to a GIS map, researchers were able to visualize the status of the flu in the country for that year.

1.2 Geographic Information System GIS

GIS (Geographical Information System), is a system designed to capture, store, manipulate, analyze, manage, and present spatial and geographical data. With vast amounts of data being generated each second, and with the increased demand for information every day, it is safe to say that the change itself seems to be the only constant of the modern world. GIS is typically a computer program that has been designed specifically to record and process data that is connected to the geography of the earth. This means that it can store and analyze large volumes of data that has to do with location, distance, time, space, terrain, and other elements of the similar nature. Those who are completely unfamiliar with the science of geography, may view GIS as of a limited use or importance in their lives, work or study, but, in reality, nothing could be further from the truth, This system is not only used by geologists or institutions such as NASA. Everyday professionals in all sorts of industries use it frequently. Hundreds of thousands of organizations in virtually every field are using GIS to make maps, communicate, perform analysis, share information, and solve complex problems around the world. Rooted in the science of geography, GIS integrates many types of data. It analyzes spatial location and organizes different layers of information into visualizations to form the digital maps. GIS hence has a unique capability to give a deeper understanding of the relationships between these layers that form the digital map, so, users can make faster and smarter decisions by using GIS. ArcGIS includes a suite of integrated applications like ArcCatalog, ArcMap, ArcToolbox, and ModelBuilder which are the tools used for this thesis.

1.3 History of GIS

Roger Tomlinson worked hard and carefully to initiate, plan, and develop the Canada Geographic Information System, which resulted in the first-computerized GIS in the world in 1963[19]. The Canadian Government had commissioned Tomlinson to create a manageable inventory of its natural resources. He envisioned the use of the computers to merge natural resources data from all provinces. Tomlinson created the design for an automated computing system to store and process large amounts of data, which enabled Canada to begin its national land-use management program. In that respect, Tomlinson is the person who coined GIS as a name.

In 1963, during a training session held at Northwestern University, Chicago, architect Howard Fisher encountered computer maps on urban planning and civil engineering produced by Edgar Harwood’s group at the University of Washington. Fisher thought for the first time to develop a mapping software program known as *Synergistic Mapping* or *SYMAP*. Fisher applied for a Ford Foundation grant to explore thematic mapping based on early *SYMAP* outputs, which was awarded in 1965. In association with Harvard providing facilities, the Ford Foundation funded $294,000 over three years to seed the Harvard Laboratory for Computer Graphics. Working with programmer Betty Benson, Fisher completed *SYMAP* for distribution in 1966. A 1968 reorganization followed Fisher reaching Harvard's mandatory retirement age and led to renaming of the laboratory to the Harvard Laboratory for Computer Graphics and Spatial Analysis. The laboratory designed and developed computer software for the analysis and the graphical display of spatial data, and distributed the resulting software to governmental agencies, educational organizations and interested professionals, and conducted research concerning the definition and analysis of spatial data. The Harvard Laboratory for Computer Graphics (HLCG) has become a research center for spatial analysis and visualization processes. Many of the early concepts for GIS and its applications were conceived at HLCG by a talented collection of geographers, planners, computer scientists, and other scientists from many different fields.

In 1969, Jack Dangermond and his wife, Laura, founded the Environmental Systems Research Institute (ESRI), Inc. in Redlands, California. As a land-use consulting firm, ESRI's early mission was to help land planners and land resource managers make environmental decisions by organizing and analyzing geographic information. These studies resulted in maps that showed constraints and opportunities for development.

In the mid-1970s, ESRI developed the polygon information overlay system (PIOS) for the San Diego Comprehensive Planning Organization. This system digitized and reported overlay areas and marked to the creation of a geographic information system (GIS). To perform analysis for an increasing number of projects more effectively, ESRI needed to automate mapping and analysis processes. To answer this need, ESRI built Arc Info, a rich toolkit for geospatial query and analysis that was released in 1982 as the first commercial GIS. It represented geographic features as vector images, and combined the display of the features like the points, the lines, and the polygons with a relational database management system that managed each feature's attributes.

The value of a geographic framework for managing and analyzing data and information became apparent. Soon, GIS was being applied to many other disciplines and industries, from utilities to public safety to insurance. Governments at all levels, businesses, and researchers began using GIS. As a global company from the beginning, ESRI initiated relationships with companies in Germany, Japan, Australia, and Canada, forming the foundation of ESRI's international network of distributors. ESRI's growth also led to the establishment of additional offices to provide local support. Washington, and Charlotte, North Carolina, were the first cities to host an ESRI office, followed quickly by eight more locations. ESRI also began building relationships with organizations that wished to build applications on top of ESRI software or support the software in specific industries. Today, more than 1,600 organizations belong to the ESRI Partner Network.

In the 1990s, faster and cheaper computers, the growth of the Internet, and new data capture techniques such as GPS spurred the growth of GIS technology. ESRI's first desktop solution, ArcView GIS, opened up the possibilities of GIS to a whole new class of users. During the late 1990s, ESRI reengineered ARC/INFO and began creating a scalable GIS platform that would work not only on the desktop, but also across the enterprise. The result was ArcGIS. The release of ArcGIS 9 in 2004 added server capabilities and a framework for developers. ArcGIS evolved into a complete platform that spanned desktop, server, and mobile devices and, with the launch of the cloud-based ArcGIS Online. ArcGIS Online, with its vast collection of basemaps and shared layers, made ESRI Story Maps possible. Esri Story Maps has a collection of templates that lets thousands of non-GIS specialists use maps to tell their stories and share them. In addition, a robust suite of software developer tools were created to enable developers to incorporate geospatial functionality into all kinds of products and processes.

1.4 Thesis Goal and Results

The goal of this thesis is to automate the process of spatial analysis as much as possible for future urban analysis applications. The city of Bergen is used as an example for evaluation. This means analysing the streets network of Bergen city by using the spatial modelling method. The analyses will be mainly on the Bergen axial map that by definition consists of a set of lines representing the streets, or in general, all of the spaces that exist inside the city. This is done by means of the *ArcToolbox* [23], which is a toolbox that contains many of the system tools provided with *ArcMap* [23] application in geographic information system. If a tool for a specific task is needed and is not in the system tools (system tools are tools have come with the GIS program already and they are ready to use), there is a support for making new tools using the existing system tools in the ModelBuilder which is a built-in tool in GIS.

The second part of the thesis aims to find out the relationship between the street-network design of the city of Bergen and energy loss of cars caused by the design of this street-network. Specifically, we aim to identify the roads or even the road-segments with designs that force the driver to use the brakes of his/her car to stop and then run the car again accelerating its speed to the previous value before stopping. The results show that there are many roads in Bergen that could be modified or redesigned to reduce energy loss.

1.5 Thesis Outline

The reader is assumed to have basic knowledge of the Geographic Information System (GIS) and geography science [15]. Below is a brief summary of the contents of each of the chapters of this thesis.

Chapter 1 – Introduction gives an overview about the spatial modelling method and how this method is used to evaluate to what extent cities are socio-economic. It gives also a historical information about GIS.

Chapter 2 – Background explains the main three applications in GIS: ArcMap, ArcCatalog, and ArcToolbox. It explains how geographical data is presented by the aid of the GIS program, how this data can be analyzed, and how geographic tasks are converted to models and scripts using the ModelBuilder tool.

Chapter 3 – Space Syntax Theory introduces the basic concepts of the space syntax theory. Based on this, we explain what the factors or key measurements that make a specific city different from another, and what the principles of the design that make the city more eco-social are. Furthermore, this chapter introduces the three types of the syntactic maps: convex, axial, and isovist map, and discuss how connectivity, integration, and control values indicate to what extent this city is socio-economically successful and what things we have to focus on to improve its design.

Chapter 4 – Spatial Modelling Method explains how this method can be used through geographic information system to give a relationship between the city design and the people's movement within the city. In this method, three elements are used: space syntax to assess the street-network integration, space matrix to assess building density, and mixed-use index (MXI) to assess the land-use pattern.

Chapter 5 – Street Network Design and Energy Consumption of Cars. This chapter provides a theoretical framework of how can we determine the points in the city's street-network that force cars to slow down or even stop and accelerate again causing loss in the car energy, and how the cross-sectional area of the car affects the loss in the energy in general. We present results from our case study of the city of Bergen.

Chapter 6 – Conclusions and future work.

Discusses the results of the applying of space syntax theory on Bergen city street network, and how we get all the building blocks in the city symbolized to high, medium and low values displayed on the map by different colors. And how can we figure out the relation between this colored presentation and any event that is happening in the city. We outline possible solutions, and provide direction for future work.

The source code for all of the scripts for this thesis and the Bergen city shapefiles data can be downloaded from: https://www.dropbox.com/home/thesis%20scripts.

Chapter 2

Background

Cities are the most important sites of socio-economic development processes, as they provide us with jobs, houses and services, and they are important centers of productivity and social activities. Furthermore, cities generally absorb two thirds of countries' population growth. In particular, bad urbanity impact and seriously threatens our socio-economic activities in our lives. This impact has many costs, lead to significant inefficiencies in the usage of local resources and it threatens the sustainability of the development process inside the cities. Urban development and environmental management therefore cannot be considered separately. Actions in the city affect the environment, and the environment in turn affects the city.

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2.1 The Urbanism and the City

Urbanism has been described as the most influential movement in architecture and city planning. There is a strong relationship between urbanism and the inner-city residents, and we have to figure out the principles of this relationship. Urbanism refers to the body of knowledge about the organization, arrangement, and human functions of cities as well as the living style that inhabitants follow inside their cities. Originally, urbanism was derived from the French sentence for "city planning", it now also refers to a philosophy that recognizes the positive intellectual, social, and physical benefits of life in well- functioning urban areas.

Urbanism has many features like the diversity of residents in terms of age and ethnicity and ways of life, the availability of public transportation or arrangements that can be accessed walking on feet, like business, shops, and entertainment centers. The principles of urbanism design are consistent with policies aimed at improving living conditions and opportunities for inner-city residents. Urbanism needs to be viewed as a strategy to be integrated within the larger array of economic, social, and community development programs attempting to strengthen and improve the quality of the life inside the city.

2.1.1 The Continuum of Urbanity

There are many models of urbanism, some of which emphasize the risks and weaknesses of urban living, and others emphasize the benefits. Green urbanism, sustainable urbanism, and ecological urbanism are some of the models that are considered nowadays as ways to improve our lives in cities and suburbs. The benefits of urbanity extend to the life quality of human beings. The continuum of urbanity, also called the urban-rural continuum. It is a conceptual framework emphasizing that rural and urban areas traditionally considered to be distinct and physically separated, are now, and will increasingly be, integrated at scales ranging from the local to the global. The integration of urban and rural places can exist along four dimensions:

- The first dimension is the livelihood, or the ways in which people support themselves materially and economically.
- The second dimension is the lifestyle, which indicates how people sort themselves into social groups, and how they behave as consumers and actors in different social networks.
- The third dimension is the long distance connections - also called teleconnections – expressed as economic investment, decision making, and the influences of livelihood and lifestyle along the continuum.
- The fourth dimension is the characteristics of place, which include the deep and persistent environmental, geological, and climatic conditions, and the cultural attributes and perceptions of specific places in the urban-rural mosaic.

Altogether, these four dimensions suggest that the degree of urbanity is not simply an expression of sophistication that is associated with the city life, but a multifaceted melding of a number of social, physical, and informational factors between people and their immediate and distant environments.

2.2 Spatial Analysis

A lot of people daily explore a digital map for a specific kind of needed information, like schools locations, parks, and demographics, for example, to determine where is the best place to buy a new house, or to find the shortest path between two places. When we look at a map, we inherently start turning that map into information in our minds by analyzing its content to make decisions. This process is called *spatial analysis*, and it means what our eyes and minds do naturally whenever we look at a map. *Spatial analysis*, or spatial data analysis, is a well-defined subset of the methods of analysis available to a project. One might define spatial analysis as a set of methods useful when the data is spatial, in other words when the data is referenced to a 2-dimensional frame. More narrowly, the Earth’s surface provides a particular instance of such a frame.

2.3 The Digital Map

A digital map is an electronic map, based on a combination of graphical elements attached to some information stored in a table. It consists of the natural objects in our life in a form of cartographic data. A digital map is scalable, it gives the ability to freely zoom in and out while keeping its same high resolution.

More accurately, there are no printed maps at the same scale as digital maps, they are always updated, and can be remotely updated at a lower cost and labor. Furthermore, digital maps have different information layers, and this layered architecture makes it possible to organise the data in groups, for example, schools layer, and hospitals layer. Digital maps are interactive maps, which means that they can respond to the user action like the mouse click or even passing the cursor over some area on the map, or user’s queries and return a result. Because the maps are digital, they occupy less physical space than old-fashioned paper maps and can easily be sent or received from the device.

2.4.1 Geographic Information System Components

An operational GIS has five components that combine to make the system works, Figure 2.1 shows these components [15]:

- Hardware. Which is the computer system on which the GIS operates. Today GIS software runs on a wide range of hardware types, from centralized computer servers to desktop computers.

- Software. The GIS software provides the functions and tools needed to store, analyze, and display geographic information such as *ArcCatalog, ArcMap, and ArcToolBox.*

- Data. Perhaps the most important component of a GIS is the data. Geographic data and related tabular data can be collected in-house, compiled to custom specifications and requirements, or occasionally purchased from a commercial data provider. A GIS can integrate spatial data with other existing data resources, often stored in a corporate DBMS. The integration of spatial data (often proprietary to the GIS software), and tabular data stored in a DBMS is a key functionality afforded by GIS.

- People. GIS technology is of limited value without the people who manage the system and develop plans for applying it to real world problems. GIS users range from technical specialists who design and maintain the system to those who use it to help them perform their everyday work.

- Methods. A successful GIS operates according to a well-designed implementation plan and business rules, which are the models and operating practices unique to each organization. As in all organizations dealing with sophisticated technology, new tools can only be used effectively if they are properly integrated into the entire business strategy and operation. To do this properly requires not only the necessary investments in hardware and software, but also in the retraining and/or hiring of personnel to utilize the new technology in the proper organizational context. Failure to implement your GIS without regard for a proper organizational commitment will result in an unsuccessful system.

Figure 2.1: GIS components [15].

2.4.2 ArcCatalog

ArcCatalog can be thought of as a window into a database of spatial data. With ArcCatalog, the user can browse, organize, distribute, and document GIS data. ArcCatalog resembles the Microsoft Windows Explorer, but it is designed for viewing geographic databases, maps, and metadata. The collection of connections that is established to the geographic data is called a Catalog. The Catalog Tree gives access to all of the Catalog's contents. In the ArcCatalog window shown in Figure 2.2, the Catalog Tree is on the left side. Geodatabase is the most popular database type that can be displayed by the ArcCatalog application, which is a database that contains the data that is connected to the digital map. It can also be a raster file, which is the most used file type in GIS programs. Scientifically, these raster files are referred to as shapefiles. From the ArcCatalog window, it is also possible to explore processing toolboxes which contain processing tools, models, and Python scripts. Figure 2.2 shows the Bergen light rail stops map after applying the buffer tool on them in ArcCatalog application. The buffer tool draws spaces around the objects in question.

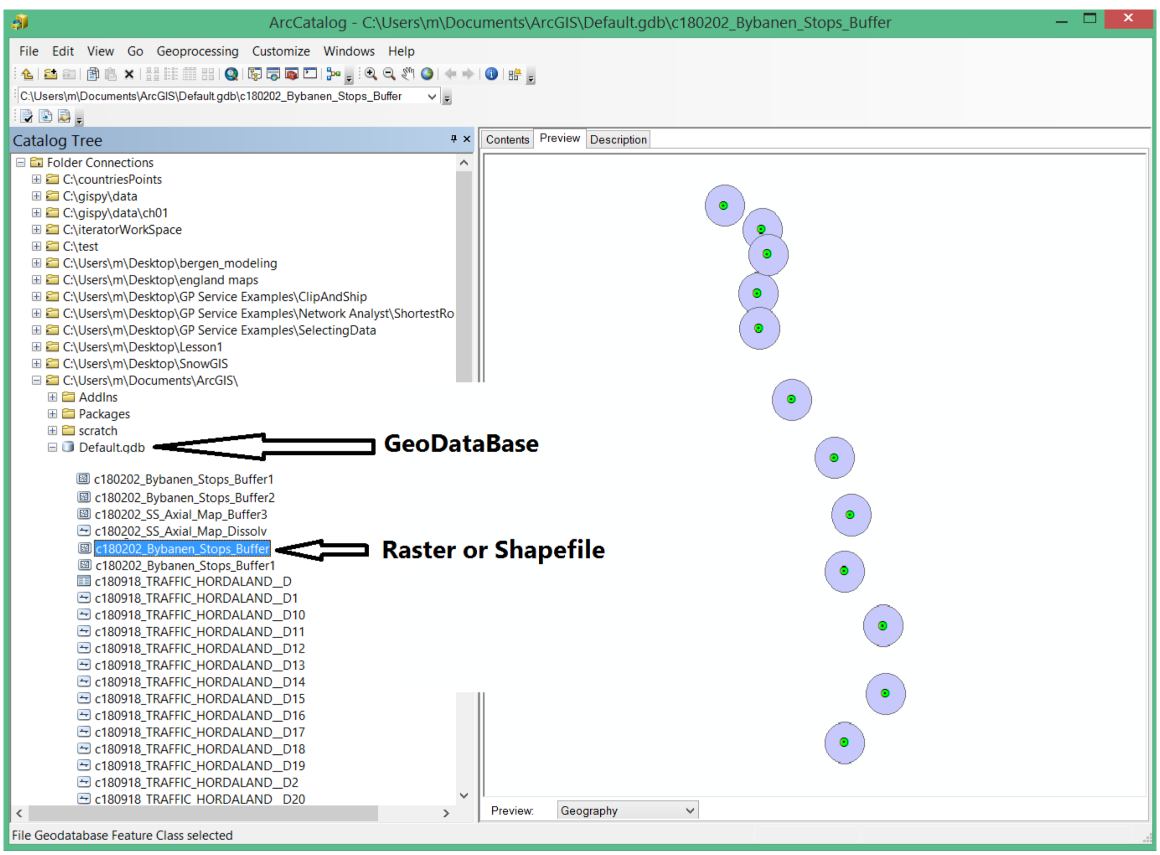


Figure 2.2: The ArcCatalog application

2.4.3 ArcMap

ArcMap is the application that is used to view and edit geographic data and create professional-quality maps, graphs, and reports. A map is the fundamental component in ArcMap. Maps help in visualizing geographic data by showing where are things and what they look like. You can drag and drop files from the ArcCatalog application window directly into ArcMap application window.

Geographic information is displayed on a map as layers, where each layer represents a particular type of feature. In ArcMap, the Table of Contents (Figure 2.3 - left), lists all the layers shown on the map. The order of layers within the Table of Contents is important, when the layer at the top of the Table of Contents is checked, it will be drawn thereby hiding the other layers. It is therefore important to put the layers that form the background of the map (such as the ocean layer) at the bottom of the Table of Contents. Figure 2.3 shows the ArcMap Application displaying the axial map for a part of the city of Bergen. An axial map is a set of lines each one represents a specific space in the city.

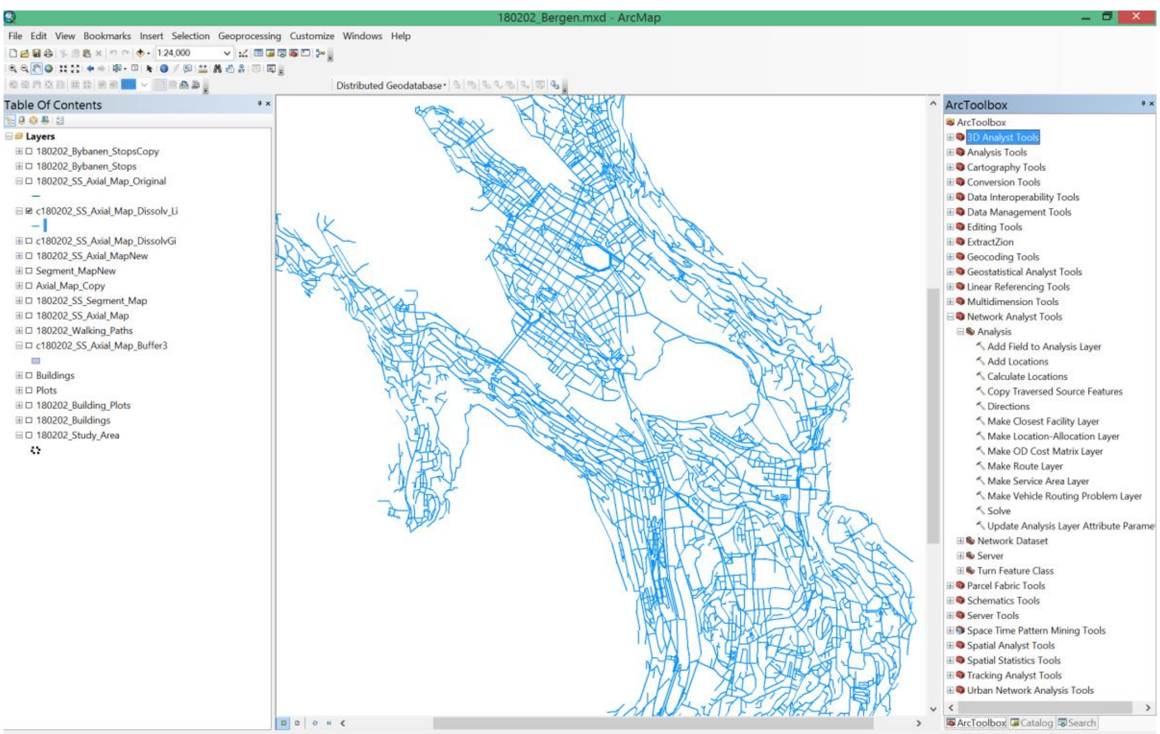


Figure 2.3: The ArcMap application

2.4.4 ArcToolbox

ArcToolbox is an integrated application in GIS developed by the Environmental Systems Research Institute (ESRI). It provides a reference to the toolboxes to facilitate user interface in ArcGIS for accessing and organizing a collection of geoprocessing tools, models and scripts.

In general, a toolbox is a container that contains all the tools required to perform any advanced task in a particular domain. Similarly, ArcToolbox is the container that has inside all the tools required to facilitate advanced geoprocessing tasks. Figure 2.4 shows the ArcToolbox contents.

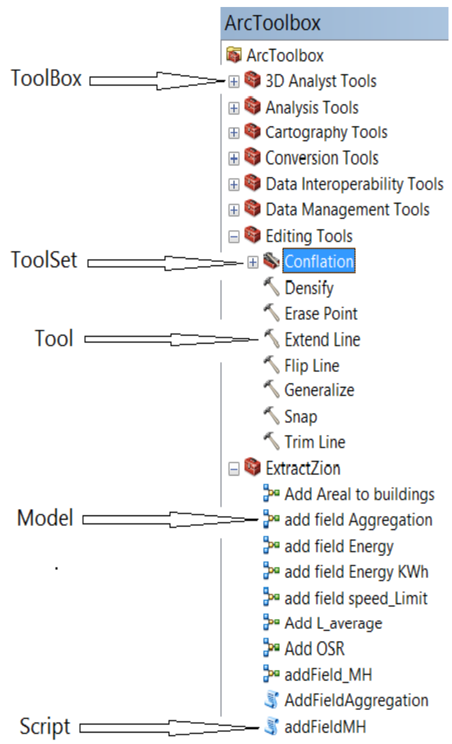


Figure 2.4: ArcToolbox Application contents

2.5 Data Representation in GIS

GIS data represents real world objects, such as roads, land use, elevation, and schools. By merging all those objects together we get a mixture that gives us a complete scene. Real objects can be divided into two abstractions: discrete objects like a house; and continuous fields like a rainfall amount. Traditionally, there are two broad methods to store data in GIS for both kinds of the previous abstractions: raster and vector images.

2.5.1 Raster Images

In computer graphics, a raster graphics or bitmap image is a dot matrix data structure, representing a rectangular grid of pixels, or points of color, viewable via a monitor, paper, or other display medium. A raster is any type of digital image, its data is represented as rows and columns of cells, and each cell has a single value. The common type of raster data in GIS is called the Digital Elevation Model (DEM) [16]. It is simply a digital representation of topography or terrain. Technically, a raster is characterized by the width and height of the image in pixels and by the number of bits per pixel (or color depth, which determines the number of colors it can represent). Raster graphics are considered as condones, from *continuous tones*, the opposite of these condones is *line work*. Rasters are implemented as vector graphics in digital systems. The advantage is that vector images can be rasterized, and raster images can be vectored by software. Figure 2.6 illustrates the difference between raster and vector images.

Figure 2.6: Vector image (left) and raster image (right).

2.5.2 Vector Images

A vector image is the most common data type used in GIS. It is referred to as a shapefile, and made up of points, lines, or polygons. A point is the location of a feature on the geographical grid, for example, a fire hydrant in the street is considered as a geographical point on the map. A line is used to show linear features like a road or a river, and the polygon is a two-dimensional feature that shows an area on the earth's surface such as the property boundaries around a university. Figure 2.5 shows the three data types of vector images: the point, the line, and the polygon.

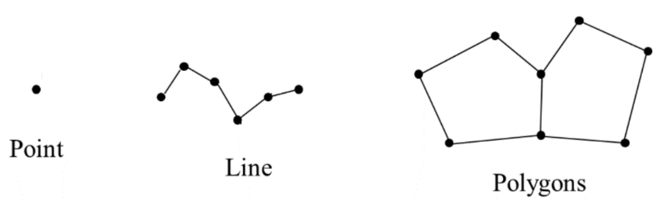


Figure 2.5: vector image data types: point, line, and polygon

Of these three types, the point shows the least amount of information and the polygon shows the most. A TIN (Triangulated Irregular Network) is a common type of vector data. It is capable of showing elevation and similar values that change consistently. The values here are connected as lines, forming an irregular network of triangles to represent the land's surface on a map, GIS is capable of translating a raster to a vector in order to make analysis and data processing operations easier. It does this by creating lines along the raster cells that have the same classification to create the vector forms of points, lines, and polygons which make up the features shown on the map.

Vector graphics use 2D point-located polygons to represent images in computer graphics, each of these points has a definite position on the x- and y- axes of the work plane and determines the direction of the path. In addition, each path has properties, including values such as color, shape, curve, thickness, and fill.

2.6 The Three GIS Views

In GIS, there are three different ways in which data can be viewed. The first is the database view. This consists of the *geodatabase* also known as the data storage structure for ArcGIS. In it, data is stored in tables, is easily accessed, and is able to be managed and manipulated to fit the terms of whatever work is being completed. The second view is the map view which is the most familiar to many people because it is essentially what many see in terms of GIS products. GIS is, in fact, a set of maps that show features and their relationships on the earth's surface and these relationships show up most clearly in the map view. The final GIS view is the model view which consists of tools that are able to draw new geographic information from existing datasets. These functions then combine the data and create a model that can provide answers for projects.

2.7 GIS Modelling Patterns

Some problems require going beyond exploring the data into quantifying relationships or formally testing hypotheses. This is where modeling comes in. Spatial modeling makes it possible to derive new information from existing data layers and to predict what might happen and where in the future. Modelling often takes into the field of developing specialized workflows through programming. When designing a model in GIS and converting this model into a Python script, it gives the ability to share it with people who are in the same field. Creating scripts and automated workflows lets you efficiently query and process large amounts of GIS data and implement more complex algorithms. Increasingly, the value of sharing methods and code through the web makes it possible to create complex workflows without the need to develop all the components. Knowledge is being shared by putting the real power of spatial analysis into the hands of more people.

2.8 Model-based Programming with Model Builder

The core idea behind geoprocessing is to make it possible to quickly and easily turn ideas into new software that can be executed, managed, modified, documented, and shared with the ArcGIS users' community. Software, in this case, means something that instructs ArcGIS to perform a task. A geoprocessing model is a new software built using an easy-to-use visual programming language called ModelBuilder. ModelBuilder can be viewed as a visual programming language in which models are designed to do the needed tasks.

When it comes to model builder, it is important to know what geoprocessing is. Geoprocessing is done by using a set of tools which are stored in ArcToolbox. The ArcToolbox dockable window is available in ArcMap and ArcCatalog applications for processing geographical and related data. The large suite of geoprocessing tools can be used to perform spatial analysis or manage GIS data in an automated way. Figure 2.7 [17] shows different data types that can be used for the geoprocessing task.

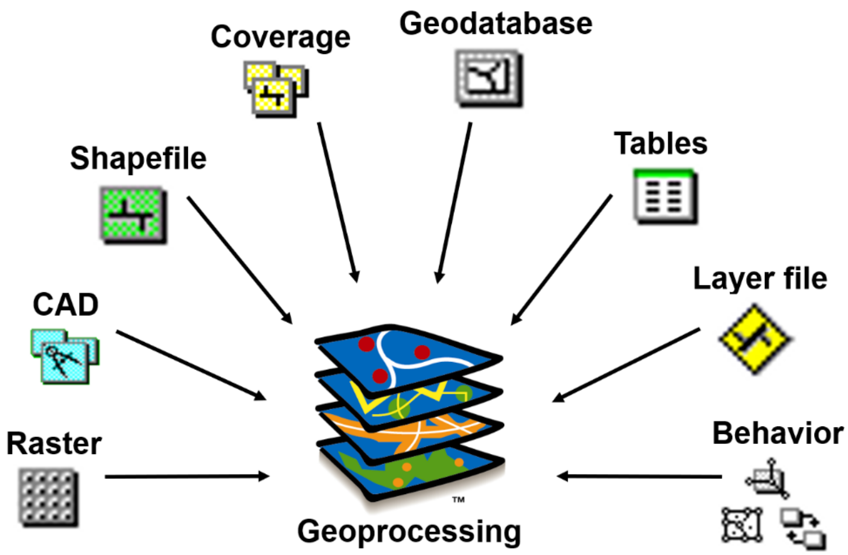


Figure 2.7: Geoprocessing Data Types.

A typical geoprocessing tool performs an operation on a dataset which is a shape file or a table for instance, and creates a resulting output dataset. For example, the buffer tool takes a map layer as an input, creates areas around the layer's features to a specified distance, and writes those areas to a new output layer. The most important thing to understand about geoprocessing in ArcGIS is that all geoprocessing operations involve the use of tools that are in the ArcToolBox. There are four ways to perform geoprocessing in GIS:

1. Using the tool's dialog by determining the input and output files and the needed parameters.
2. Using the built-in command line in GIS environment.
3. Using the Model Builder which is a model-based programming language interface.
4. Using python language libraries and scripts that are designed for GIS like *arcpy* library.

Figure 2.8 illustrates the four different ways to do a geoprocessing task.

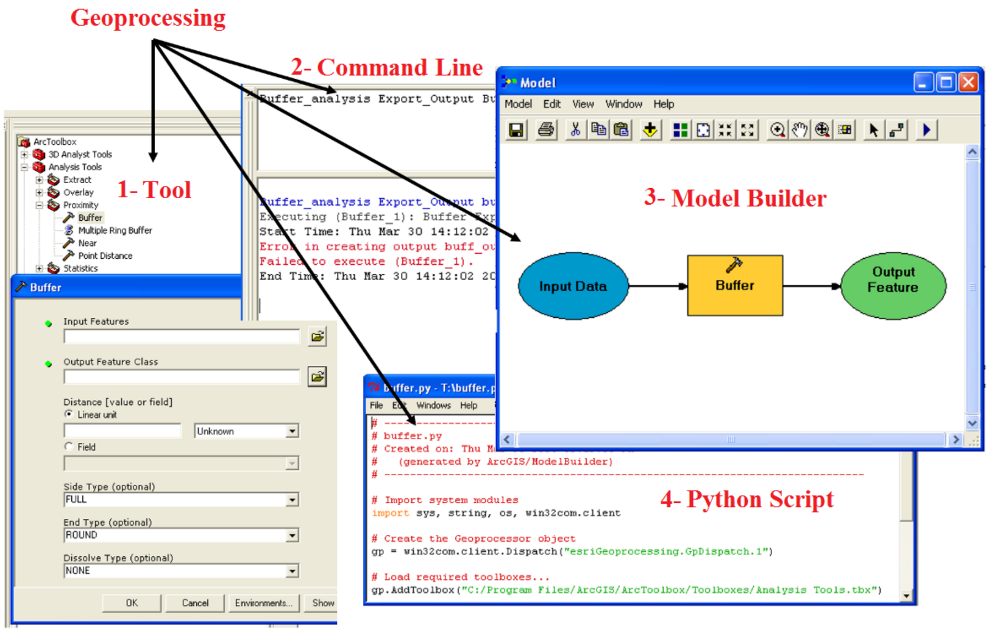


Figure 2.8: The four ways to do Geoprocessing in GIS.

2.8.1 Model Builder

Model Builder is an ArcMap extension used to create, edit, and manage models. Models are workflows that string together sequences of geoprocessing tools, feeding the output of one tool into another tool as input. The Model Builder can also be thought of as a visual programming for building workflows. It provides advanced methods for extending GIS functionality by enabling the creation and sharing models as tools. Figure 2.8 shows how to create a new model starting from the ArcToolbox.

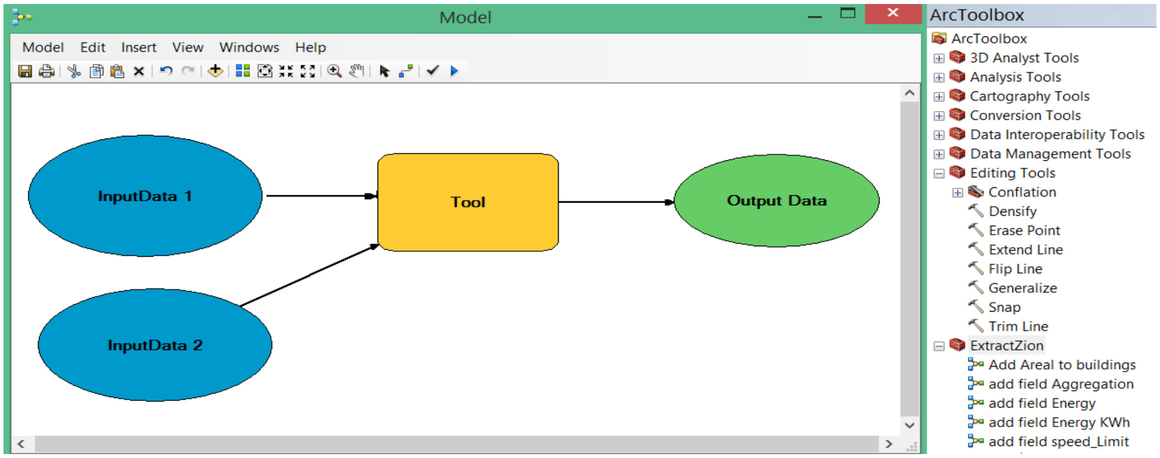


Figure 2.9: Model Builder window (left) and ArcToolBox (right).

A model in its simplest form consists of at least one process, which has at least one tool, that can accept one or more input files and only one output file. Figure 2.10 shows that the process consists of input data and output data and a tool. A tool can be of two types: system tool or custom tool. The system tool is a built-in tool which comes with the GIS software and is ready to use, whereas a custom tool is the tool that was designed by a GIS developer.

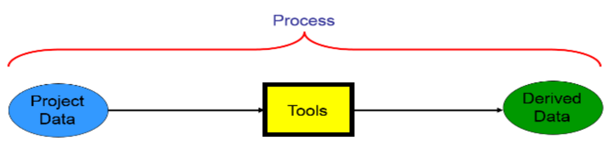


Figure 2.10: process components in Model Builder

A process has three states as shown in Figure 2.11. The first state is when the tool does not have the proper input values, in this case nothing is colored, and everything is in the white color. The second state is when everything is ready to run, which means that the tool has got its proper inputs. At that point, the tool's color will turn into yellow color and the output to the green. The third state is when the model is successfully executed. Then, the yellow tool rectangle and the green oval output get shadows under their boxes. Figure 2.11 illustrates the three states of the model.

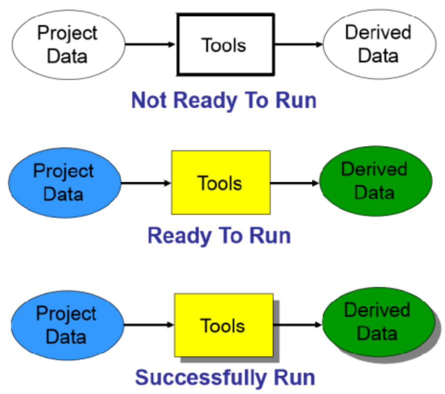


Figure 2.11: the three states of the Process

The ModelBuilder has advantages and disadvantages. Some of the advantages are that model builder is an efficient tool for automation of repetitive and time consuming geoprocessing tasks. It reduces the risk of human errors. It does not need a lot of programming skills, especially for basic models. It is very simple to share customized models with other people through the ArcToolbox or even as a Python script. On the other hand, ModelBuilder has some disadvantages. The most important one is that the models that were developed in ModelBuilder can be “bulky”, whereas the model/tool that has been developed in Python or another programming language may be more efficient. Another limit is that the models that were developed in earlier releases of model builder can cause unexpected conflicts in later releases.

Chapter 3

The Space Syntax Theory

"A good city is like a good party, people stay longer than really necessary, because they are enjoying themselves"

Jan Gehl

The space syntax theory [1] studies the relationship between urban form and social and economic activities in a city. More importantly, it considers how can we come to terms with these relations or indicate the factors or the key measurements of this relationship. Some cities are more social and economic successful than others. The space syntax theory studies these issues and considers key measurements that should be taken into consideration when building new cities or even reconstructing old ones. These questions are not only for social scientists across disciplines, but also for architects.

The term space syntax holds a set of theories and techniques for the analysis of spatial configurations, and to clarify how the built environment relates to society. It explains how the buildings that we construct are not only a product of the social processes, but also play a role in producing new social forms.

The general idea is that spaces can be broken down into components, analyzed as networks of choices, and then represented as maps and graphs that describe the relative connectivity and integration values of those spaces.

The idea originated from Bill Hillier [1], a professor at the Bartlett School of Architecture, University College London (UCL) and Julienne Hanson and colleagues in the late 1970s and early 1980s as a tool to help urban planners simulate the likely social effects of their designs. They wanted to find out why social housing of the 1960s and 70s in the United Kingdom was not working; why a sense of community had not developed. They wanted to find means of describing and analyzing how the layout of houses interacted with the space. Together they wrote a book called "The Social Logic of Space" (1984).

Their work resolved many problems with understanding the entire structure of a city as a network with different spatial and urban dimensions. This has a major impact on understanding the pedestrians' movement within the city. Hillier said: "there must be a relationship between the number of pedestrians and the spatial integration measure of any space".

3.1 Basic Concepts of the Space Syntax Theory

The most important contribution of the space syntax theory to the field of urban planning and city designing lies in identifying the keys or the connections between spatial layout and the social, economic and environmental performance of the place. While space syntax covers many topics like vision, isovists, and indoor space, in this study the focus will be on the application of space syntax to urban spaces in a city, i.e., on a single property which is spatial configuration of the outdoor space in the city. In this context, spaces can be categorized in three types: convex space, axial space, and isovist space.

3.1.1 Convex Space

A convex space [4] is also called convex polygon. It is a polygon with the property that no line drawn between two points within that polygon goes outside of the polygon. In other words, no line crosses its perimeter.

Fig. 3.1 (left) illustrates a convex set which looks somewhat like a deformed circle. The (black) line segment joining points x and y lies completely within the (green) set. Since this is true for any points x and y within the set that we might choose, the set is convex. Fig. 3.1 (right) illustrates a non-convex set. Since the red part of the (black and red) line-segment joining the points x and y lies outside of the (green) set, the set is non-convex.

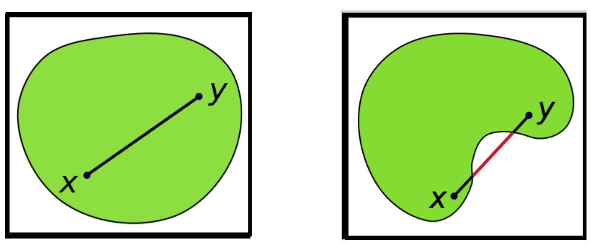


Fig. 3.1: convex set (left) and non-convex set (concave set) (right)

3.1.2 Axial Space

An axial space or an axial line, is the longest line which connects convex polygons together. It is a straight line linked to the notion of visibility that can be followed by feet. Fig. 3.2(b) shows the axial spaces or the axial lines of a city's street network. Fig. 3.2 shows the four steps required in the process of converting the city streets into a graph [2]. The first step (Fig. 3.2(a)) is to delineate the continuous open space of the relevant area and break it down into convex spaces. The second step (Fig. 3.2(b)) is to create the axial map by identifying the smallest connected network of straight lines passing through such convex spaces. The third step (Fig. 3.2(c)) is to split the axial lines at intersections to create a street segment map. And finally, the forth step (Fig. 3.2(d)) is to generate the graph by converting each street segment in the street segment map into a vertex with edges representing its direct links to other vertices.

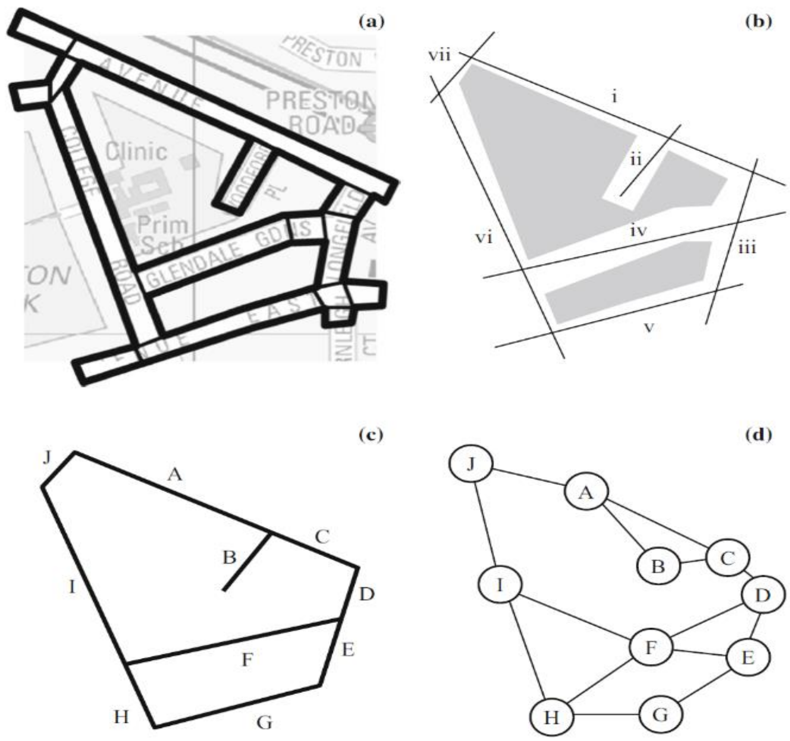


Fig. 3.2: Process of generating a street segment network in space syntax.

3.1.3 Isovist Space

An isovist space (illustrated in Fig. 3.4) is the set of all points that could be visible from a specific point in a space with the respect to the environment. Since the isovist space is built upon a point, the associated view changes as the point's position changes, just as our notion of urban space changes as we walk through it. Isovist spaces are frequently used in many fields of visibility studies like wireless network design, landscape management and analysis, pedestrian access or security. Fig 3.3 shows how the area that can be viewed (the gray color) changes according to the position of the view point [5]. And in Fig. 3.4 [6], the isovist space is the pink polygon that could be viewed from the blue point, while purple polygons represent the buildings blocks in the city.

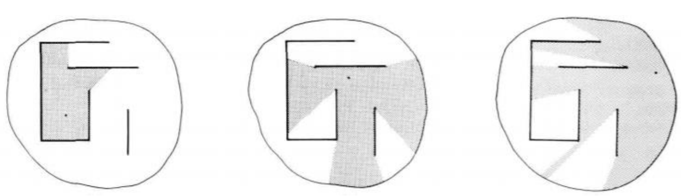


Fig. 3.3. Three different isovist spaces from three different views.

Fig. 3.4: Isovist space.

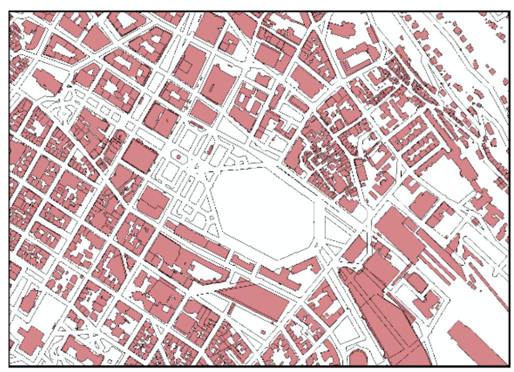
3.2 Types of Syntactic Maps

Spatial structures are represented using syntactic maps. Using the same terminology as in the previous section, there are three types of syntactic maps: convex maps, axial maps, and the isovist maps.

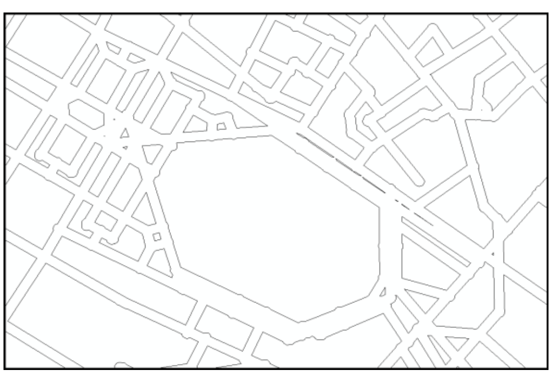
3.2.1 Convex Maps

Convex maps portray the least number of convex polygons and the connections between these polygons. These polygons connect to each other to fully cover whole the studied area. Fig. 3.5(a) shows the standard map of the main part of the city of Bergen, Fig. 3.5(b) shows the buildings and streets layers of that part, Fig. 3.5(c) shows the convex map of the streets network, and Fig. 3.5(d) shows the axial map of that part.

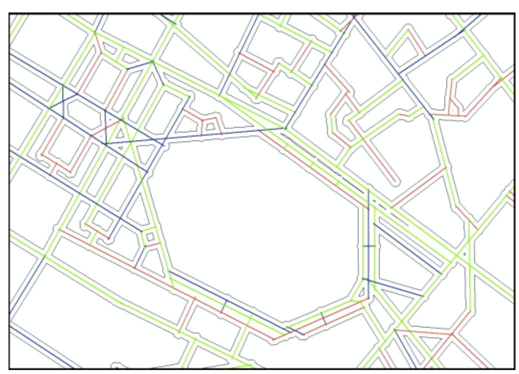
(a)



(b)



(c)

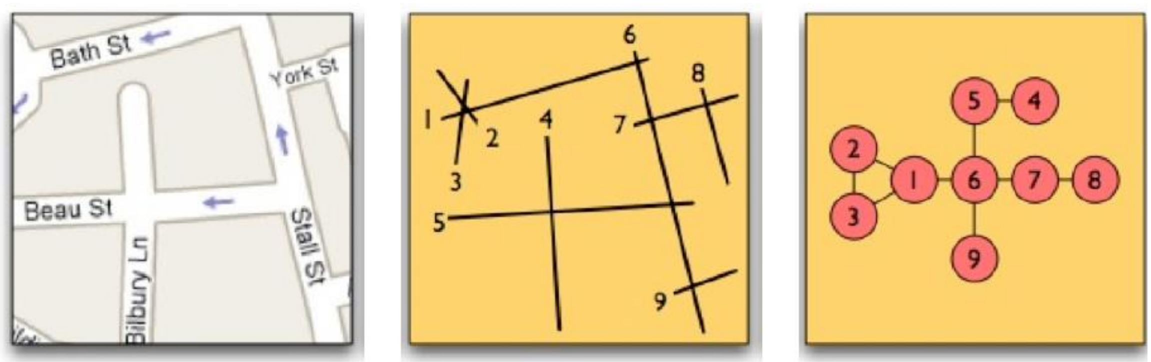


(d)

Fig. 3.5: (a) Part of the standard map of Bergen city, (b) buildings and streets layers map, (c) the convex map and (d) the axial map.

3.2.2 Axial Maps

The fundamental idea of the space syntax theory is that every city can be represented as an axial map. A city's axial map can be derived by simply drawing the set of least and longest straight lines such that all open spaces (as shown in Fig. 3.6(b)), have an axial lines passing through them. These lines are called as axial map as shown in Fig. 3.6(b). These axial lines can be considered as members of a larger family of axial representations (often called skeletons) of 2D images. The next step of the analysis process is to transform the axial map of Fig. 3.6(b) into a graph as the one shown in Fig. 3.6(c) by representing each axial line as a node, and linking these nodes (axes) that are intersected in the axial map. This graph representation is the edge-vertex dual of how we intuitively represent maps: streets as edges and street intersections as nodes. Space syntax uses the opposite way: streets become nodes, and intersections become links. Each street, irrespective of its width, length, and location, is represented by a single node in the graph. This is an extremely powerful representation, because it enables researchers to identify concrete metrics for each street in a city. This is achieved by carrying out analysis of the graph, and deriving numerous metrics for each node (i.e. street).



a b c

Fig. 3.6: a) standard city map, b) axial map, c) the graph representation.

An axial map describes the least number of axial lines covering all convex spaces of the site and their connections. When an axial map is transformed into a graph, it becomes easier to be read, study and analyse. A graph is a figure that shows the relationship of accessibility between all the convex spaces or the axial spaces in the area. Fig. 3.7[8] shows four different buildings and their justified graphs.

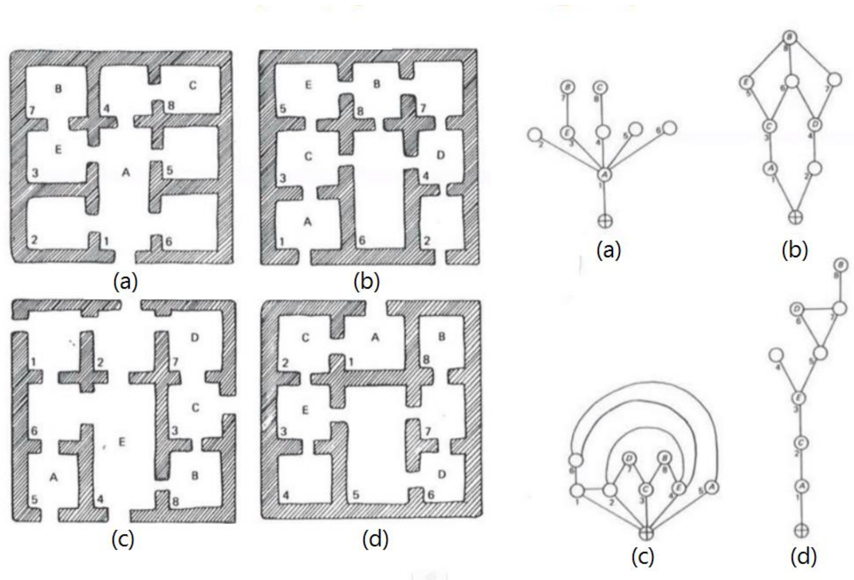


Fig. 3.7: four different buildings (left) and their justified graphs (right).

When calculating depth values of each vertex in the graph, a syntactic step is used, which is the direct connection or the relationship between a space and its directly connected neighbors. In an axial map, a syntactic step is the change of the direction from one line to another. In Fig. 3.7 (a), going from the root vertex to the c vertex for example takes 3 syntactic steps.

The depth metric of each vertex in the graph is an important metric in space syntax theory, as it defines a topological distance in the graph (see Fig. 3.8 [3]). It counts the least number of syntactic steps that are needed to reach one vertex from another. If two lines are directly connected, the distance between them is equal to one, and the distance between two indirectly connected lines is calculated according to the shortest path between them.

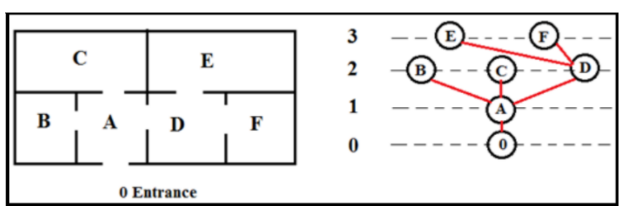


Fig. 3.8: a building (left) and its justified graph with its depth levels (right).

After creating the graph that represents the building and assigning the depth values to its vertices, we get the justified graph, which is a graph that shows a specific space placed at the bottom as the root, and the other spaces that are one-syntactic step away from the root space are placed in the first level of the graph, spaces that are two- spaces away are placed in the second level and so on. These graphs help to understand the overall depth of the site seen from one specific point in the space, (street). Fig 3.8 shows the depth levels of the vertices (the spaces) in the justified graph, and the values of these levels are represented as numbers (1, 2, 3, 4) beside the discontinuous lines, so the depth value of the C vertex is 2. Justified graph can be bush-like graph as Fig. 3.7(a) shows, or treelike graph as shown in Fig. 3.7 (b), depending on the graph structure. [3]

3.2.3 Isovist Maps

An isovist map represents all visible areas from the different convex spaces of the city. Fig. 3.9 illustrates one of the city isovists in 3D that could be seen from a specific point in the street. [11].

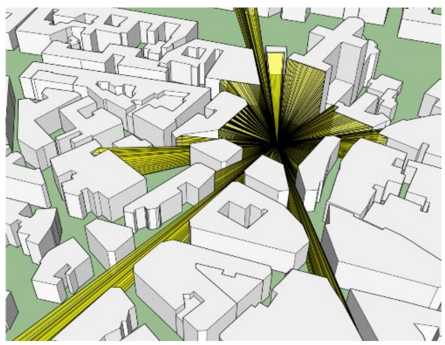


Fig.3.9: A 3D isovist of a part of a map.

3.3 Space Syntax Key Metrics

On the basis of visual representations, it is possible to see that each space has certain syntactic properties (Hillier, Hanson, 1984, chapter 4)[1]: it will either be distributed with respect to other spaces (has more than one path to them) or nondistributed (has only one path), and it will be either symmetric with respect to other spaces i.e., having the same relation to each other, or asymmetric, i.e., not have the same relation to each other, in the sense of one controlling the way to another with respect to a third.

The relation is symmetric if a is to b as b is to a with respect to c, meaning that neither a nor b control permeability (access) to each other like in Fig. 3.10 (a). The relation is asymmetric if a is not to b as b is to a, in the sense that one controls permeability to the other one from some third space c, like in Fig. 3.10 (c). The relation is distributed if there is more than one independent route from a to b including one passing through a third space c (i.e. if a space has more than one locus of control with respect to another) like in Fig. 3.10 (a). The relation is nondistributed if there is some space c, through which any route from a to b must pass, like in Fig. 3.10 (b).
So, we can say that in Fig. 3.10 (a), a and b are in a symmetric and distributed relationship with respect to c; while in Fig. 3.10 (b), a and b are in a symmetric and nondistributed relation with respect to c. Fig. 3.10 (c) shows a and b in a nondistributed and asymmetric relationship with respect

to c. Fig. 3.10 (d) shows a slightly more complicated case, where a and b are symmetric to each other with respect to c, but d is an asymmetric relation to both with respect to c. This example therefore illustrates a relation that is both asymmetric and distributed. Fig. 3.10 (e) inverts this and places d in a nondistributed and asymmetric relation to a and b, which still remain symmetric to each other with respect to d (or to c).

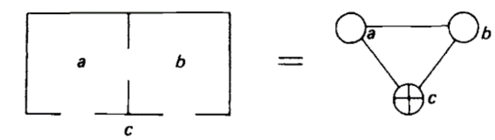


Fig. 3.10 (a): a and b in a symmetric and distributed relationship with respect to c.

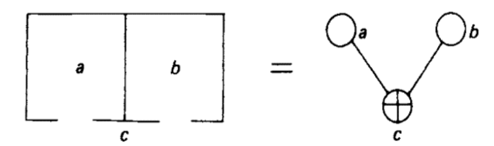


Fig. 3.10 (b): a and b in a symmetric and nondistributed relationship with respect to c.

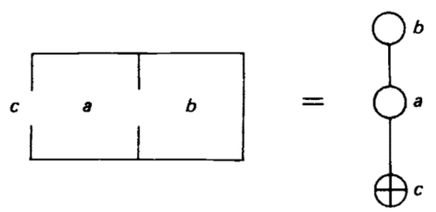


Fig. 3.10 (c): a and b in a nondistributed and asymmetric relationship with respect to c.

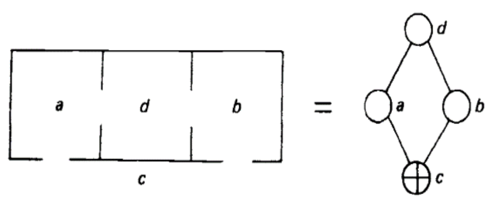


Fig. 3.10 (d): a and b are symmetric to each other with respect to c, but d is an asymmetric relation to both with respect to c

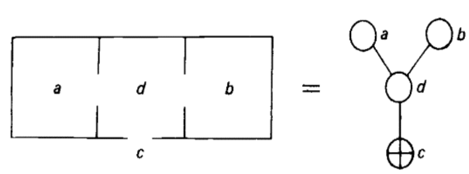


Fig. 3.10 (e): d in a nondistributed and asymmetric relation to a and b, which still remain symmetric to each other with respect to d (or to c).

There are many syntactic measurements that can be calculated in the space syntax theory, connectivity and integration are the most significant two of them.

3.3.1 Connectivity

The connectivity is the measure of how well an axial line is intersected by other lines. There is no non-intersected line in urban environment, which means that every space is accessible from every other space in the city. The length of the line has correlation to connectivity index, saying that the long lines are more likely to be intersected by other lines than the shorter ones. The connectivity metric measures the number of depths that are directly connected to a space. And because of being directly connected, it is called a local metric or a local measure. The connectivity of a node can be defined as the number of other directly connected nodes. Fig.3.6 (b) shows that the connectivity value of line number 6 (node 6 in the graph) is equal to 4 as it intersects with lines number: 1,5,7,9.

3.3.2 Integration

The concept of integration indicates the degree to which a line is integrated, or segregated, from a system as a whole. In other words, integration measures how many turns have to be made from a street segment to reach all the other street segments in the street network, using shortest paths. If the number of turns required for reaching all segments in the graph is analyzed, it is said that the analysis process is done to measure integration at radius n. The first intersecting segment requires only one turn, the second two turns and so on. Street segments that require the fewest turns to reach all other streets are called 'most integrated' and are usually represented with hotter colors, such as red or yellow. Integration can also be analyzed in local scale instead of the scale of the whole network. In the case of radius 4, for instance, only four turns are counted departing from each street segment. Theoretically, the integration measure shows the cognitive complexity of reaching a street, and is often argued to 'predict' the pedestrian use of a street: the easier it is to reach a street, the more popular it should be.

The integration of a space is a function of the number of lines and changes in direction required to go from that space to all other spaces in the spatial system. The term *depth* is used rather than distance to illustrate how far a given space is from another space. The integration value of a line is a mathematical way to express the depth of a line from all other lines in the system. These values significantly differ from one line to the next, but are one of the most significant properties of architectural, urban, and landscape spatial configurations (Hillier and Hanson, 1984; 1996; 1998). A space is *integrated* when the other spaces have a relative in relation to that space, and a space is *segregated* when the other spaces have a relative *depth* in relation to it.

Depending on how well a space is connected, the axial map can be colored from red to blue, Red lines represent very well connected/integrated space and blue lines are not well connected/most segregated, and to show something in between, a spectrum from red to blue is used. This is illustrated in Fig. 3.11 (4) [9].

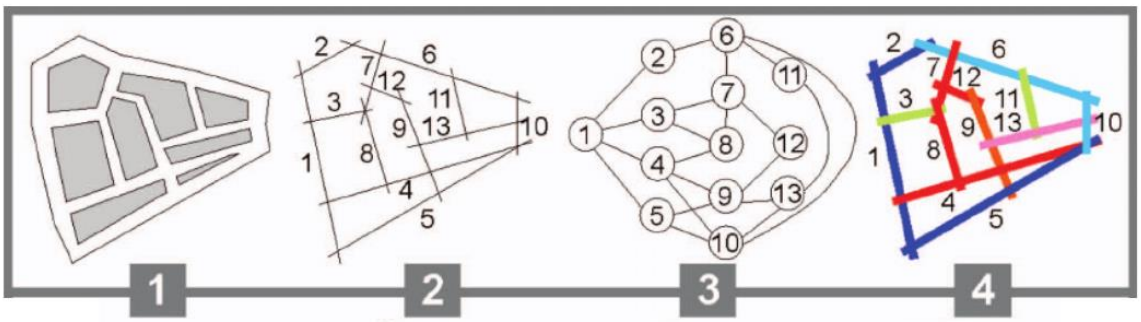


Fig. 3.11: Convex map 1, Axial map 2, the graph 3, axial map with integrated values (colors) 4.

By the aid of the DepthMapX application, which is a software that produces the axial map starting from the convex map, we get the results shown in Fig. 3.12 for Bergen city. It shows where the most integrated spaces (city streets network) are located. The red lines are the places that have more pedestrians than the blue ones.

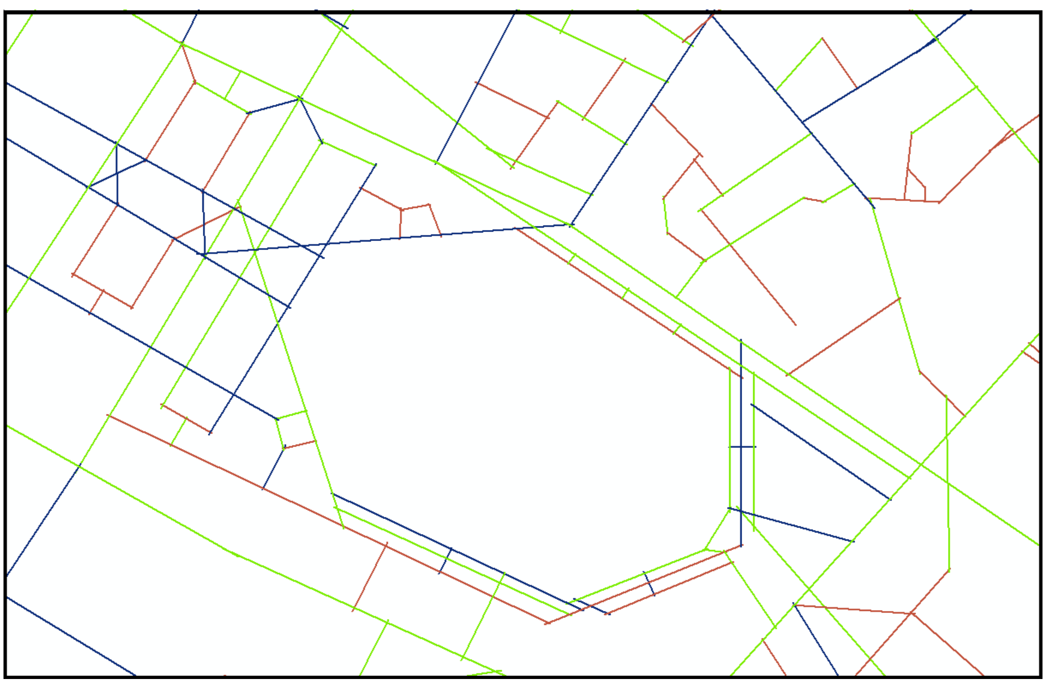


Fig. 3.12: A part of the axial map of the city of Bergen.

The axial or the convex segments are either many steps – that is, deep - from the carrier (the node with "+" sign in Fig.3.10 (a), which is the outer space of the studied building), or a few steps that is, shallow - from the carrier. Relations of depth necessarily involve the notion of asymmetry, since spaces can only be far from (deep) from other spaces if it is necessary to pass through intervening spaces to arrive at them.

The measure of relative asymmetry (RA) generalises this by comparing how deep the system is from a particular point with how deep or shallow it theoretically could be, the least depth exists when all spaces are directly connected to the original space, and the most depth exists when all spaces are arranged in a linear sequence away from the original space, i.e., every additional space in the system adds one more level of depth. To calculate relative asymmetry from any point, the mean depth of the system is calculated from the space by assigning a depth value to each space according to how many spaces it is away from the original space, summing these values and dividing by the number of spaces in the system less one (the original space). The relative asymmetry can then be calculated as:

$$\text{Relative Asymmetry:} \quad RA_i = 2(MD_i - 1) / (k - 2)$$

Where MD_i is the mean depth of space number (i), MD_i is given by the following formula:

$$MD_i = \sum_{j=1}^{k} (d_{ij} / (k - 1))$$

Where k is the number of spaces in the whole system (number of the vertices in the graph). And d_{ij} is the length of a shortest path between nodes i and j; (the number of links between vertex i and vertex j).When those calculations are applied for example to the vertex number 4 in graph (a) of the previous Fig 3.7, we get MD_4 equal to = 0.25.

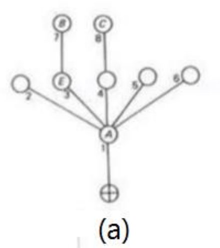


Fig 3.7 graph (a).

$$MD_4 = \sum_{j=1}^{k} (d_{4j} / (k - 1)) = (1+1+2+2+2+2+2+3) / 8 = 1.875$$

$$\begin{aligned} RA_4 &= 2(MD_4 - 1) / (k - 2) \\ &= 2(1.875-1) / 7 \\ &= 0.25 \end{aligned}$$

And in the same way:

RA_0	0.321
RA_1	0.071
RA_2	0.321
RA_3	0.250
RA_4	0.250
RA_5	0.321
RA_6	0.321
RA_7	0.500
RA_8	0.500

The RA value is between 0 and 1, and low values like RA_1 indicate a space from which the system is shallow, that is a space which tends to integrate the system, while high values like RA_7 indicate a space which tends to be segregated from the system.
Relative asymmetry (or relative depth) can therefore be thought of more simply as the measure of integration. Note that a low value means a space with a high degree of integration.

3.3.3 Control Value

A control value is a dynamic local measure. It measures the degree to which a space controls access to its immediate neighbors taking into account the number of alternative connections that each of these neighbors has. Each space has a certain number of immediate neighbors n. Therefore, each space gives to each of its immediate neighbours the value l/n, and then these values are summed for each receiving space to give the control value of that space. In effect, each space is partitioning one unit of value among its neighbours and getting back a certain amount from its neighbours. Spaces which have a control value greater than 1 will be strong control, those below 1 will be weak control spaces. Note that control is a local measure, since it only takes into account relations between a space and its immediate neighbours, whereas integration is a global measure since it takes into account the relations of a space to every other space in the system. In Fig. 3.6 (b), the control value for line number 6 is $1/3+1/2+1/2+1/1=2.33$. And the control value for line number 4 is 1/2 since line number 4 intersects only with one line which is line number 5, and this line connects directly with only 2 lines (lines number 4 and 6) so n is 2, and while the control value is equal to $0.5<1$ then this line (vertex) is considered as a weak control space.

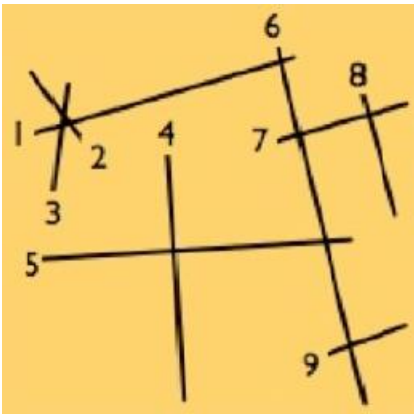


Fig. 3.6(b): A part of the axial map.

Chapter 4

The Spatial Modelling Method

Cities can be identified as problems of organized complexity, and they arise by a countable set of interrelated factors which contribute in different ways to the emergent behavior of cities. In this chapter, the focus is on the spatial aspect of the organized complexity of cities by taking a space syntax interpretation of cities as networks of interconnecting spatial elements. The space will be considered the main influential factor in the formation process of the cities. Spatial modelling method through the space syntax theory has proved a relationship approximating 70% between the spatial structure and the pedestrian movement within cities (Hillier1996a, 50). The high values of spatial integration play an important role in magnifying the socio-economic activity in cities by increasing the probability of pass to and pass through movement.

A spatial modelling method uses geographic information system to combine the analyses of three constituent elements of urban form. The aim is to produce a spatial classification system for various types of urban areas, and reveal how they perform socio-economically. In the proposed method the three elements considered are:

- Space syntax, to assess street-network integration,
- Space matrix, to assess building density, and
- Mixed-use index (MXI), to assess the land-use pattern.

The method is used to suggest ways of improving socio-economic performance in urban areas. For example, a spatial diagnosis can be made for new towns suffering from a lack of vibrant street life. The method helps to reveal the interdependences of street-network integration, building density, and land-use mixture in urban transformation processes.

The first element of the spatial modelling method (space syntax) can be applied to measure various street-network integration values, or how any given street spatially relates to other streets. Measurements of building mass can be considered using the second element which is the space matrix method. This makes it possible to quantify building types and building density, and non-built space. Finally, land-use pattern can be quantified using the third element (MXI), to measure the degree of land-use diversity. Combining these three measurements makes it possible to quantitatively describe the spatial properties of urban form, thereby providing a new classification system for spatial types of urban areas in relation to their socio-economic performance. Viewed in this way, a high degree of accessibility, density and land-use diversity would generally mean a high degree of socio-economic performance, and *vice versa*.

4.1 Space Syntax Method

The general purpose of this chapter is to automate the process of analysis on urban environments that promotes informed decision-making for planners. The main tasks are to quantify, manipulate, aggregate and visualise the data. Subsequently, calculations need to be made that can be used to determine the type of planning strategy to apply in a specific location based on the results of the analyses. The space syntax method shows how the spatial integration of the streets network affects the movement flows, the location of the economic activities, and the amount of the street life.

Three analysis methods are used. First, the Space Syntax method is used to make calculations on the street network configuration. Second, the Space matrix method quantifies building density and building typology. Third, the degree of functional mix is quantified using the Mixed-Use Index method. Combining the three previous methods and showing the results in one map demonstrates to what extent a specific city is urban.

First of all, we need to prepare the data for street network configuration for Bergen city. This means to find out how well or poorly a street is integrated in the street network. This can be calculated by a computer program called *Depthmap*. The axial lines that represent the lines (the streets) of the sight are supplied as two shapefiles (two digital maps), the first one is the *axialmap* file that contains the fields: Global Integration (GI) and Local Integration (LI), and the second one is the *segmentmap* file, which contains the fields: Metric Step Depth High Radius (MH) and Metric Step Depth Low Radius (ML). We need the four fields GI, LI, MH, ML to be in a single map, so we can do the calculations on them. These two shapefiles (we can consider the shapefile as a table) do not have any shared column to be used as a primary and a secondary key columns to perform the join relationship, so, for this kind of problems, GIS provides us with the spatial join tool which is a tool that joins attributes from one map (table) to another based on the spatial location.

After finishing this join operation, we get the four attribute columns GI, LI, MH and ML in a single shapefile. Now we add a new column named [aggregate], and calculate its value in the following manner: $((GI \cdot LI) + (MH \cdot ML))$ as it is shown in the table that is below the map in figure 4.1.

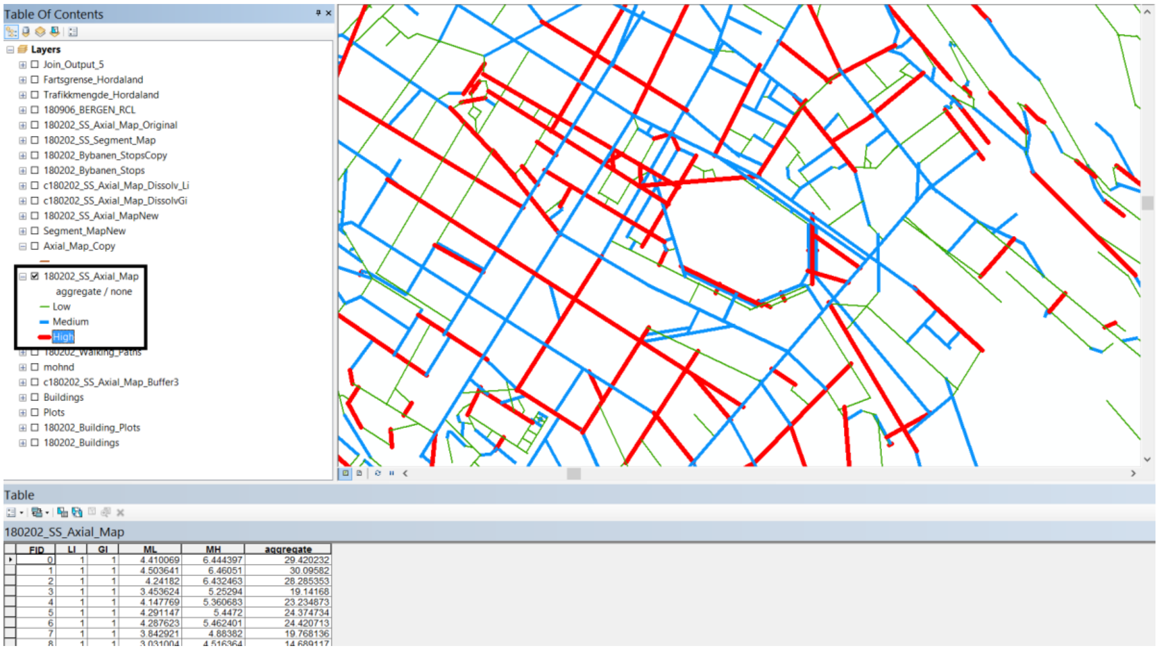


Figure 4.1: Aggregated values categorized into low, medium, and high values.

After having the aggregated values for every axial line. We can categorize them to low, medium, and high values. We have used the model builder application to design the model that performs the *add field* operation to the map as it is shown in the Figure 4.2.

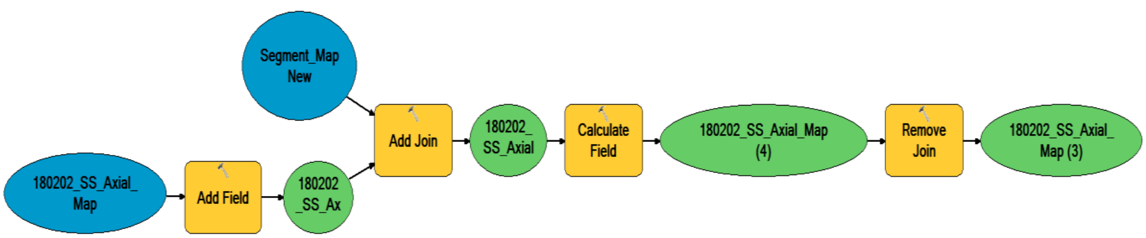


Figure 4.2 Model to add a column (field) to a map (table) and calculate its value.

We have used the *calculate field* tool (the yellow rectangle in the model above) to calculate the value of the field we have just added, which is [aggregate]. By double clicking on the *calculate field* tool, it opens a dialogue box giving the chance to write the desired calculation expression, for example, the expression for aggregate field is shown in Figure 4.3.

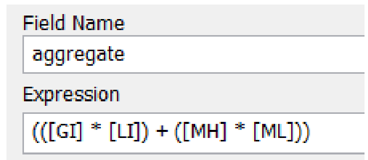


Figure 4.3: *Calculate Field* tool to calculate field [integrate].

To implement this model in the Python language, GIS provides with a built-in interface for Python scripting. Figure 4.4 shows the script that does the same work the previous model does.

```
1  import arcpy
2
3  # Local variables:
4  v180202_SS_Axial_Map = "180202_SS_Axial_Map"
5  v180202_SS_Axial_Map__2_ = v180202_SS_Axial_Map
6  Axial_MapNew__3_ = v180202_SS_Axial_Map__2_
7  Segment_MapNew = "Segment_MapNew"
8  v180202_SS_Axial_Map__4_ = Axial_MapNew__3_
9  v180202_SS_Axial_Map__3_ = v180202_SS_Axial_Map__4_
10 h=arcpy.GetParameterAsText(0)
11
12 # Process: Add Field
13 arcpy.AddField_management(v180202_SS_Axial_Map, h, "DOUBLE", "", "", "", "",
   "NULLABLE", "NON_REQUIRED", "")
14
15 # Process: Add Join
16 arcpy.AddJoin_management(v180202_SS_Axial_Map__2_, "FID", Segment_MapNew,
   "FID", "KEEP_ALL")
17
18 # Process: Calculate Field
19 arcpy.CalculateField_management(Axial_MapNew__3_, h,
   "[Segment_MapNew.05_MH_R558]", "VB", "")
20
21 # Process: Remove Join
22 arcpy.RemoveJoin_management(v180202_SS_Axial_Map__4_, "")
```

Figure 4.4: Adding field Python script.

As we see from this script, we use the arcpy library (line 1), which is the most popular Python library used to perform GIS tasks. We use local variables (lines 4-10), which represent the input and output files. Every tool in the model is represented in the script as a process. For example, line 16 represents the AddJoin process that takes the parameter (v180202_SS_Axial_Map__2_) as an input file and the parameter (Segment_MapNew) as the joining file, and the (FID) parameter which is the key that the two parameter files (the two tables) use to perform the join relationship.

4.2 Building Density

Building density and building type can be represented simultaneously using the spacematrix method. In this way it is possible to quantify variables such as intensity, compactness, non-built space, and building height. The floor space index (FSI) on the y-axis gives an indication of an area's built intensity or plot ratio. The ground space index (GSI) on the x-axis indicates the building coverage (ground-floor area). The spacematrix method divides building types into low-rise, mid-rise and high-rise, based on the floors number in the building. It also separates buildings into point type, strip type, and block type based on the construction forms. Thereafter, the whole built environment can be divided into nine categories: A, B, C, D, G, H, I, E, and F, as Figure 4.6 shows.

Building density and building typology for Bergen city can be quantified by three parameters: Floor Space Index (FSI), Ground Space Index (GSI) and Open Space Ratio (OSR). The calculations require floor space B ([BRUKSAREAL]) and plot area A ([AREAL]) and the number of floors (L) in each building. The values are calculated by the following formulas:

FSI = B/A
GSI = ((B/L) /A)
OSR = (1-[GSI]) / (FSI)

Four new attribute columns are added with names: [FSI], [GSI], [OSR] and [BLDCLASS]. By using the formulas above their values are calculated depending on the [BRUKSAREAL], [AREAL] and [F_ETASJER] columns. Then [BLDCLASS] column value is calculated using the script shown in Figure 4.5 which is written inside the "calculate field" tool of the model according to the formulas in Figure 4.6.

VB Script for [BLDCLASS] Field

```
dim b
if ((([L_average]<7 and [L_average]>3 and [GSI]<0.3 and [GSI]>0.2) or([L_average]<7 and [L_average]>3 and [GSI]>0.3 ))or(([L_average]>7 and  [GSI]>0.3 ))) then
b = "High"

elseif ((([L_average]<7 and [L_average]>3 and [GSI]<0.2 and [GSI]>0) or([L_average]>7 and [GSI]>0 and [GSI]<0.2 ))or(([L_average]>7 and  [GSI]<0.3 and [GSI]>0.2 ))) then
b ="Medium"

elseif ((([L_average]<3 and [GSI]<0.2 and [GSI]>0) or([L_average]<3 and [GSI]>0.2 and [GSI]<0.3 ))or(([L_average]<3 and [GSI]>0.3 ))) then
b ="Low"

end if
```

With BLDCLASS=b

Figure 4.5: Building classes script.

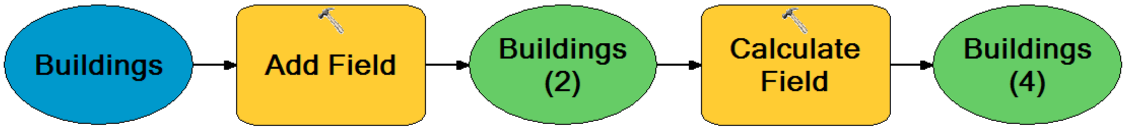


Figure 4.6 Model to calculate Building Class [BLDCLASS].

Building density and type (Spacematrix)

High

$$\text{Types } E, F, I = \begin{cases} E: \text{ mid-rise, stripe type is } 3 < L_{\text{average}} < 7 \text{ and } 0.2 < \text{GSI} < 0.3 \\ F: \text{ mid-rise, block type is } 3 < L_{\text{average}} < 7 \text{ and GSI } \gg 0.3 \\ I: \text{ high-rise, block type is } L_{\text{average}} \gg 7 \text{ and GSI } \gg 0.3 \end{cases}$$

Medium

$$\text{Types } D, G, H = \begin{cases} D: \text{ mid-rise, point type is } 3 < L_{\text{average}} < 7 \text{ and } 0 < \text{GSI} \ll 0.2 \\ G: \text{ high-rise, point type is } L_{\text{average}} \gg 7 \text{ and } 0 \text{ GSI } \ll 0.2 \\ H: \text{ high-rise, stripe type is } L_{\text{average}} \gg 7 \text{ and } 0.2 < \text{GSI} < 0.3 \end{cases}$$

Low

$$\text{Types } A, B, C = \begin{cases} A: \text{ low-rise, point type is } L_{\text{average}} \ll 3 \text{ and } 0 < \text{GSI} \ll 0.2 \\ B: \text{ low-rise, stripe type is } L_{\text{average}} \ll 3 \text{ and } 0.2 < \text{GSI} < 0.3 \\ C: \text{ low-rise, block type is } L_{\text{average}} \ll 3 \text{ and GSI } \gg 0.3 \end{cases}$$

$\text{FSI}_x = F_x/A_x$; F_x = gross floor area of (m^2) in street block x; A_x = gross area of block x (m^2);
$\text{GSI}_x = B_x/A_x$; B_x = gross building footprint of (m^2) in street block x; $L_{\text{average}} = \text{FSI}_x/\text{GSI}_x$;

Figure 4.7. The nine categories of building density and building typology [20].

After running the model shown in Figure 4.6, we get the results that determine the three building classes explained in Figure 4.7 which are the high, the medium, and the low as shown in Fig. 4.8

L_average	FSI	BLDCLASS
2	0.186854	Low
4	0.295387	Medium
1	0.09894	Low
1	0.105696	Low
1	0.06782	Low
4	0.288346	Medium
2	0.453644	Low
1	0.077969	Low
4	0.002629	Medium
4	0.367384	Medium
4	0.681133	Medium
4	0.359602	Medium
4	1.678064	High
2	0.671563	Low
4	1.682489	High
1	0.027012	Low
4	1.549925	High
2	2.205726	Low

Figure 4.8: An extract of the building class [BLDCLASS] field values

After we get building class values, we categorize these values to high, medium, low values and display them on the map as shown in Figure 4.9.

Figure 4.9. Categorizing the building class field values into high, medium, low values.

The building data for the city of Bergen was taken from the Bergen municipality’s database and from its data attributes we have used only: building number, building type, and function type attributes. For the Spacematrix calculations, we use the following attributes of buildings layer:

BRUKSAREAL (floor space in m2),
F_ETASJER (number of floors).

To make the Spacematrix calculations, we need the plot sizes. This field is represented in the building-plots layer under the name of AREAL, to do that, The spatial join tool is used between The Building, and the Building-plots layers.

To generate the attribute data for FSI (Floor Space Index) and GSI (Ground Space Index) and GI (Global Integration) the scripts in figures 4.10, 4.11, and 4.12 are used.

```
dim f
if [BRUKSAREAL] > “0” then
f = [BRUKSAREAL] / [AREAL]
else f = “X”
end if
```
With FSI = f

Figure 4.10: The FSI calculating script.

```
dim g
if [BRUKSAREAL] / [AREAL] > “50”
then
g = “X”
elseif  [BRUKSAREAL] > “0” then
g = [BRUKSAREAL] / [AREAL]
elseif  [AREAL] < “25” then
g = “X”
end if
```
With GSI = g

Figure 4.11: The GSI calculating script.

```
dim gi
if [01_GI_R0] < "0,269310" then
gi = "1"
elseif ( [01_GI_R0] < "0,388777" and [01_GI_R0] > "0,269309")
then
gi = "2"
elseif [01_GI_R0] > "0,388776" then
gi = "3"
end if
```
With GI = gi

Figure 4.12: The GI calculating script.

In the same way, we calculate values for the field local integration (LI). Then we aggregate (LI) and (GI) by multiplying their values:

[GI] * [LI]

So we get the results as shown in the following matrix

[GI] * [LI]	LI=1(LOW)	LI=2(MID)	LI=3(HIGH)
GI=1(LOW)	1	2	3
GI=2(MID)	2	4	6
GI=3(HIGH)	3	6	9

4.3- Mixed-use Index (MXI)

The MXI quantifies the degree of land-use mixture. It measures the functional mix, based on the percentages of gross floor area of dwellings, working places, and commercial amenities occupying all the floors of the urban blocks. ‘Housing’ encompasses various residential buildings, including apartments, condominiums and townhouses. ‘Working places’ includes offices, factories and laboratories. ‘Amenities’ includes commercial activities (such as retailing), educational activities (such as schools and universities) and leisure activities (such as stadiums, cinemas, and museums).

These values are assigned in the following way. Space syntax utilizes two types of spatial integration analyses, and whether the overall results can be classified as a high, medium or low depends on the formulas in Figure 4.13 [20]. For example, an overall high value in space syntax represents either two high values, or one high value and one medium value. The overall medium value represents either two medium values or one high value and one low value; and the overall low value represents either two low values or one medium value and one low value. In the spacematrix analyses, the midrise strip and high-rise block type have high values. The low-rise block and mid-rise or high-rise point and strip types have medium values, and the low-rise point and low-rise strip types have low values.

In the MXI analyses, monofunctional areas have low values, bifunctional areas have medium values, and multifunctional areas have high values as Figure 4.13 illustrates.

Functional mixture (MXI)

High — Mixed (*triplefunctional*)

$$= \begin{cases} 5\% < \frac{A_{\text{housing}}}{A_{\text{gross}}}\% < 20\% \text{ and } \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{working}}}{A_{\text{gross}}}\% > 5\% \\ 5\% < \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% < 20\% \text{ and } \frac{A_{\text{housing}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{working}}}{A_{\text{gross}}}\% > 5\% \\ 5\% < \frac{A_{\text{working}}}{A_{\text{gross}}}\% < 20\% \text{ and } \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{housing}}}{A_{\text{gross}}}\% > 5\% \end{cases}$$

$$\text{Highly} - \text{mxied} = \frac{A_{\text{housing}}}{A_{\text{gross}}}\% \gg 20\% \text{ and } \frac{A_{\text{working}}}{A_{\text{gross}}}\% \gg 20\% \text{ and } \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% \gg 20\%$$

Medium — Bifunctional

$$= \begin{cases} \text{Housing + Amenities: } \frac{A_{\text{housing}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{working}}}{A_{\text{gross}}}\% \ll \\ \text{Housing + working: } \frac{A_{\text{housing}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{working}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% \ll 5 \\ \text{Amenities + working: } \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{working}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{housing}}}{A_{\text{gross}}}\% \ll \end{cases}$$

Low

$$\text{Monofuncional} = \frac{A_{\text{housing}}}{A_{\text{gross}}}\% \gg 95\% \text{or} \frac{A_{\text{working}}}{A_{\text{gross}}}\% \gg 95\% \text{ or } \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% \gg 95\%\, or\, \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% \gg 95\%$$

A_{housing} = the gross housing floor space (m^2); A_{working} = the gross working floor space (m^2); $A_{\text{amenities}}$ = the gross floor space of all commercial and public facilities (m^2). A_{gross} = the gross floor space of the analysed area

Figure 4.13. The High, Medium, Low Mixed-use Index (MXI) for Functional Mixture. [20]

In ArcMap application the buildings layer (buildings shapefile or map), we add three columns houses, amenities, and offices to the shapefile's attached table, and by the help of the description in the file named *(9.3 Bygningstyper basert på NS 3457 – fullversjon*) that has been obtained from the Norwegian Mapping Authority [28], we know what is the meaning of each code, Fig 4.14 illustrates a part of that file, for example the code 612 refers to a kindergarten building (barnehage).

600 Kultur- og forskningsbygning

610 Skolebygning

Dette gjelder bygninger for barne- og ungdomsskoler og videregående skoler inkl. gym

Typen skal deles i:

611 Lekepark

Lekepark: Sted for opphold for barn 1-5 år. Oftest 4-5 timers tilbud, men kan også være
nærmest som spiserom å betrakte. En lekepark er i stor grad basert på at barna skal v

612 Barnehage

Barnehage: Sted for opphold for barn 1 - 5 år. Kan være heldag og halvdag, og det er kr
avdelinger, spiserom/hvilerom for de ansatte og kjøkken. Styrt av *Barnehageloven*.

613 Barneskole

Skolebygning for skoleklassene 1-7, for barn i alderen 6-12 år.

614 Ungdomsskole

Skolebygning for skoleklassene 8-5, for barn i alderen 13-15 år.

Fig 4.14: a sample of the buildings name and code [28].

According to these codes, we distinguish every block in the city weather it is a house or an office or one of the amenities places. After that we calculate the percentage of the houses and offices and the amenities in every building block. By applying the formulas in fig. 4.13 that illustrates the MIX function, we get those building blocks classified into high, medium and low values, Fig 4.15 shows a punch of the results.

$\frac{A_{housing}}{A_{gross}}$	$\frac{A_{working}}{A_{gross}}$	$\frac{A_{amenities}}{A_{gross}}$	MIX
50	0	50	Medium
50	0	50	Medium
50	0	50	Medium
80	0	20	Medium
50	0	50	Medium
75	0	25	Medium
50	0	50	Medium
100	0	0	Low
100	0	0	Low
0	0	100	Low
100	0	0	Low
0	100	0	Low
0	0	100	Low
0	0	100	Low
100	0	0	Low
100	0	0	Low
100	0	0	Low

Fig 4.15: An extract of the results of the MIX function.

Now we have the three methods, street network integration, building class, and building mixture function (MIX) represented as one of the three values, high, medium, and low. By combining all the those quantitative data from space syntax, spacematrix and MXI analyses as it is shown in Figure 4.16, we get the opportunity to propose a new classification system of various types of urban areas.

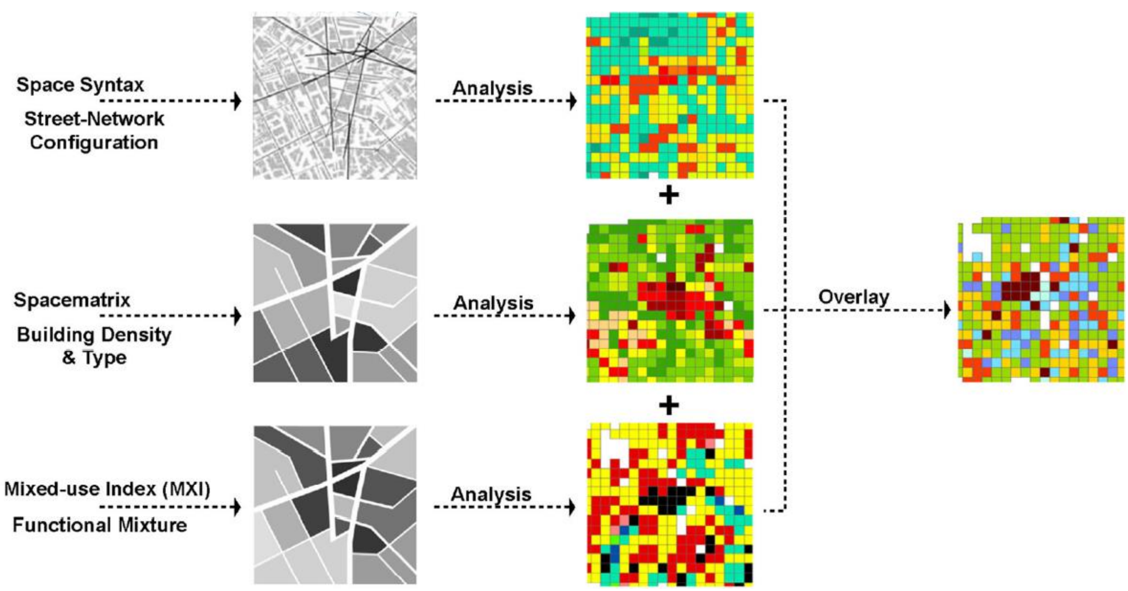


Figure 4.16: The combination of essential morphological elements measured by Space Syntax, Spacematrix, and MXI [20].

We can classify the final result, which is after the overlaying step in Fig.4.16 that represents the built environment, into the following three groups: ‘balanced with low-values’, ‘unbalanced with mixed-values’, and ‘balanced with high values.’ As it is shown in Figure 4.17. [20] ‘Balanced’ word reflects similar values in the space syntax, spacematrix and MXI measurements (that is, similarly high or similarly low values), whereas 'unbalanced' reflects the existence of significant differences between the values of the three measurements. Based on this, seven categories are proposed, ranging from suburban to highly urban areas. The terms used in this classification matrix, for instance 'suburban' and 'urban', differ from their standard use in urban geography. Instead, this matrix reflects the spatial features of urban form as part of a continuous rural-turban gradient and also reveals the area's related socio-economic performance. For instance, 'suburban' areas belong to the 'balanced with low-values' group because they have either three low values, or two low values and one medium value in all spatial measurements, which suggests a low degree of socio-economic performance (for example, silent, mono-functional urban areas). Conversely, 'highly-urban' areas belong to the 'balanced with high-values' group because they have either three high values, or two high values and one medium value in all measurements, which suggests a high degree of socioeconomic performance. 'In-between areas' (with high values) belong to the 'unbalanced with mixed-values' group because these areas have a mixture of high and low values in the space syntax, spacematrix and MXI analyses. These areas are defined as 'in-between' areas since their spatial parameters tend to support a higher degree of socio-economic performance than the 'suburban' areas but a lower performance than the 'highly-urban' areas. Moreover, such 'unbalanced' areas contain one or two relatively low values in the three spatial measurements, which also indicates their potential to transform.

Urban forms can be classified into seven types shown in Figure 4.17, ranked from all low values to all high values in the three morphological elements (the three spatial measurements).

Balanced versus unbalanced	*Type*	*The value distribution of the street-network configuration, building density and type, and functional mixture degree*	*Example*
Balanced with low values	I	L/L/L; M/L/L; L/L/M; L/M/L	
	II	L/M/M; M/L/M; M/M/L	
Unbalanced	III	H/L/L; L/H/L; L/L/H	
	IV	H/M/L; M/H/L; L/M/H; H/L/M; L/H/M; M/L/H	
	V	H/H/L; H/L/H; L/H/H	
Balanced with high values	VI	M/M/H; M/H/M; H/M/M; M/M/M	
	VII	H/H/H; H/M/H; M/H/H; H/H/M	

L low value, *M* medium value, *H* high value.

Figure 4.17. The seven different types of urban form via space syntax theory. [20]

The attribute TYPEKODE of the buildings layer has been used for the MXI function calculations. Using this function, buildings can be in three categories: amenities, housing and offices. So, three columns are added to buildings layer with names: AMENITIES, HOUSING and OFFICES. To generate the data for these three columns, the scripts shown in Figures 4.18, 4.19, 4.20 below are used. The numbers that are in these scripts, like 200 and 300 are the codes that Bergen municipality uses in their databases and these codes 200 and 300 for instance, indicate that the building unit belongs to the amenities category, and the attribute [F_BOENHETE] represents a living or a working unit.

Amenities

```
dim a
if ((( [TYPEKODE] > "200") and ( [TYPEKODE] < "300") and ( [F_BOENHETE] = "0"))
or (( [TYPEKODE] > "320") and ( [F_BOENHETE] = "0"))) then
a = [F_ETASJER]
elseif
((( [TYPEKODE] > "200") and ( [TYPEKODE] < "300") and ( [F_BOENHETE] >"0")) or
(( [TYPEKODE] > "320") and ( [F_BOENHETE] > "0"))) then
a = "1"
else a = "0"
end if
```

With Amenities = a

Figure 4.18: The Amenities script

Offices

```
dim o
if (([TYPEKODE] < "320") and ([TYPEKODE] > "300" and ([F_BOENHETE] = "0")))
then
o = [F_ETASJER]
elseif (([TYPEKODE] < "320") and ([TYPEKODE] > "300") and ([F_BOENHETE] > "0"))
then
o = "1"
else o = "0"
end if
```

With offices = o

Figure 4.19: The Offices script

Housing

```
dim h
if [TYPEKODE] < "200" and [F_BOENHETE] > "0" then
h = [F_ETASJER]
elseif [TYPEKODE] > "200" and [F_BOENHETE] > "0" then
h = ([F_ETASJER] - ( [AMENITIES] + [OFFICES]))
else h = "0"
end if
```

With Housing = h

Figure 4.20: The Housing script

The last script (Housing), should be run at the end because it depends on the two previous scripts Amenities and Offices.

The MIX function script is shown in the figure 4.21, and the [AhouOnAgg] parameter represents the percentage of the gross housing floor space over the gross floor space of the analyzed area.

```
dim m
if ((([AhouOnAgg]<20 and [AhouOnAgg]>5)and ( [AamOnAgg]>5)and ([AoffOnAgg]>5)) or
   (([AamOnAgg]<20)and([AamOnAgg]>5)and([AhouOnAgg]>5)and([AoffOnAgg]>5)) or
   (([AoffOnAgg]<20)and ([AoffOnAgg]>5) and ([AhouOnAgg]>5) and ([AamOnAgg]>5)))
    then
        m = "High"

elseif ((([AhouOnAgg]>5) and ([AamOnAgg]>5) and ([AoffOnAgg]<5)) or (([AhouOnAgg]>5)
        and ([AoffOnAgg]>5) and ([AamOnAgg]<5)) or
        (([AamOnAgg]>5) and ([AoffOnAgg]>5) and ([AhouOnAgg]<5))) then
        m ="Medium"

elseif (([AhouOnAgg]>95) or ([AoffOnAgg]>95) or ([AamOnAgg]>95)) then
        m ="Low"

end if
```

Figure 4.21:The MIX function script.

Chapter 5

Street Network Design and Energy Consumption

The energy challenge is one of the biggest issues facing Europe today. In 2012, EU-28 final energy consumption reached approximately 15% of the world's energy consumption (Eurostat, 2012) [24]. A third of this amount was consumed by the transport sector (31.7%), the most energy demanding sector. Long-term forecast to 2030 suggest that energy consumption in Europe will increase in all major sectors and that the transport sector will experience the most rapid growth, increasing by 28% between 2000 and 2030 (European Commission, 2003) [25].

Despite significant advances in transport technology and fuel formulation, transport energy consumption has increased in most EU countries over the last three decades. This increase in consumption occurred as a result of factors such as higher car ownership, a growth in automobile use and an increase in vehicle distances traveled. As travel and land-use are a function of one another, it is often hypothesized that changing urban structure can result in changes in energy consumption. Understanding how different land use characteristics may influence travel behavior and the corresponding energy consumption is crucial for planners and policy makers in order to develop strategic actions to shrink the environmental footprint of the urban transportation sector. The aim of this chapter is to review the connections between land use, travel behavior and energy consumption. In particular, this chapter seeks to identify the determinants of transport energy consumption in urban areas [26].

Understanding that the design of the street network of the city influences the energy consumption is a crucial issue for city planners in order to develop better designs to reduce this energy consumption in the future.

5.1 Kinetic Energy of the Car

When a car travels a 100 km distance it uses about 80 kWh of energy [13]. Below we analyse the properties of a car that affect energy consumption and relate it to street network design. The energy in a fossil-fueled car is consumed by four main elements:

1. Speeding up and slowing down using the brakes,
2. Air resistance,
3. Rolling resistance,
4. Heat: 75% of the energy is transformed into heat to the car's engine and radiator.

Rolling resistance will be ignored in this study. Assume that the driver accelerates rapidly up to a speed v, and maintains that speed for a distance d, which is the distance between traffic lights, stop signs, or congestion events. Figure 5.1 illustrates this. When the driver applies the brakes, all kinetic energy is turned into heat in the brakes. Once the driver resumes driving again, the car accelerates back up to the previous speed v at which it was moving before stopping. This acceleration gives the car kinetic energy again.

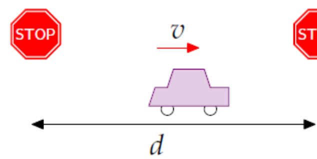


Figure 5.1: A car moves at speed v between stops separated by a distance d [13].

Car-manufacturing engineers work hard on car design to find the best shapes and materials to produce smoother and gentler bend cars. We work here in the opposite way, we work to design cities with street networks that save as much as possible of the car energy. Such a street network is called a car-friendly street network.

The car loses its kinetic energy not only because of the brakes, there are also other sources of energy consumption. While the car is moving, it makes air swirl behind it, forming a tube of swirling air. This swirling air moves at a speed similar to v. One question is which of these two forms of energy is bigger: kinetic energy of the swirling air, or the heat that is produced when the driver wants to stop and applies the brakes. Kinetic energy is given by the following formula:

$$\text{Kinetic energy} = ½\ \mathrm{m}v^2$$

As an example, the kinetic energy of a car with mass m = 1000 kg that moves 100 km per hour (or v = 28m/s) is:

$$½\ \mathrm{m}v^2 \simeq 390\ 000\ \mathrm{J} \simeq 0.1\ \mathrm{kWh}$$

When the driver applies the brakes and later resumes to the previous speed v every duration d/v, the rate at which energy is lost into the brakes is shown in equation (A.1) [13].

$$\frac{\text{kinetic energy}}{\text{time between braking events}} = \frac{1/2\ \ mcv^2}{\mathrm{d/v}} = \frac{1/2\ \ mcv^3}{\mathrm{d}} \quad \text{(A.1)}$$

Where m_c is the mass of the car.

Figure 5.2 shows a car moving at speed v. It creates behind it a tube of swirling air. The cross-sectional area of the tube is similar to the frontal area of the car, and the speed at which the air in the tube swirls is approximately equal to v.

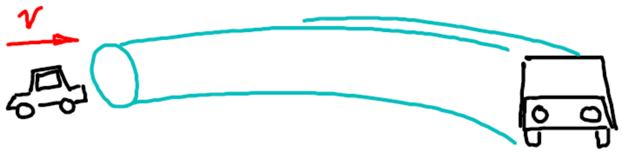


Figure 5.2 the swirling air tube that the car makes [13].

The volume of the cylinder is the area of the cylinder base multiplying by the height of the cylinder. The cylinder base here is the cross-sectional area of the tube and the cylinder's height is equal to d.

The tube of air created in a time *t* has a volume *Avt*, where *A* is the cross-sectional area of the tube, which is similar to the area of the front view of the car. For a streamlined car, *A* is usually smaller than the frontal area A_{car}. The ratio of the tube's effective cross-sectional area to the car area is called the drag coefficient C_d.

5.2 Drag Coefficient Effect

It is known that friction causes mechanical energy loss, but moving objects can lose energy through fluid drag. Imagine a car speeding down the highway. It is not just losing energy to the rolling resistance of the wheels on the road. The air is resisting it too. The power required to move the air out of the way depends on the density of the air, the cross-sectional area of the car, and the cube of car velocity. This is shown in Figure 5.3(a). Drag coefficient also affects, which is a way of quantifying aerodynamics. If the car has a more streamlined shape or less surface friction, it will disturb less air as shown in Figure 5.3(b).

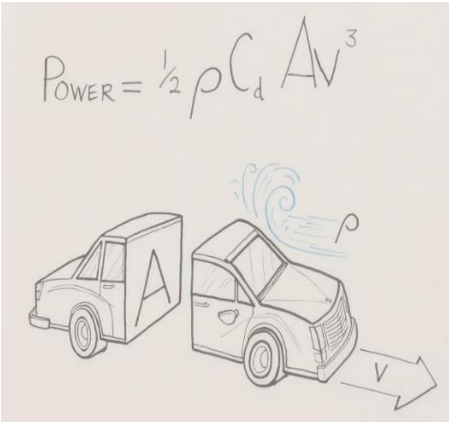


Figure 5.3(a): Cross-sectional area effect [27].

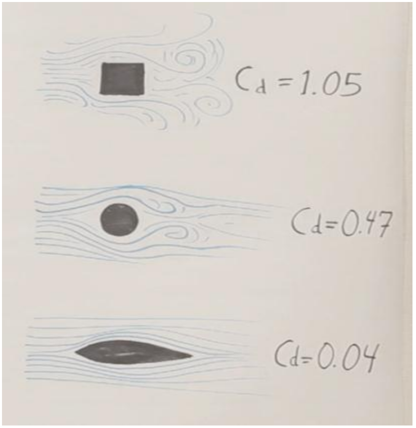


Figure 5.3(b): Drag coefficient effect [27].

Most cars have a drag coefficient of about 0.3[13], while a streamlined car might have half that. The shape of a car can be improved, but the equation in Figure 5.3(a) shows that the most effective way to reduce the loss from drag is to reduce speed. Since velocity is cubed, doubling the velocity means eight times more power lost to drag.

Moving an object through a fluid causes energy loss. And moving fluid through an object does the same (the fluid here represents the air in our case). With the right design thinking, these losses can be cut drastically. For that reason, car-designers always try to design the car in a way that it looks like some forms from the nature. Figure 5.4 illustrates how car designers have copied the design of the pigeon's body.

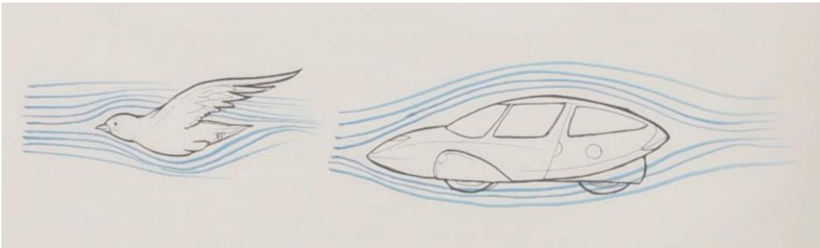


Figure 5.4: copying designs from the nature [27].

Figure 5.5 [12] shows different types of cars each has different drag coefficient Cd, and because of the air resistance, the power consumed by a car is proportional to the cross-sectional area of the car when the car travels at a high speed on a motorway, and to the car's mass during town driving when the speed is lower, SOPHIE IV car in Figure 5.5 (the modern one in the front), has a much smaller cross-sectional area than the typical passengers cars (those that are in the back), helping to reduce the aerodynamic drag coefficient value C_d.

Figure 5.5. Reducing the aerodynamic drag coefficient Cd. [12].

In the following equations [13], A denotes the effective area of the car, $C_d A_{car}$, The tube has mass $m_{air} = \rho Avt$ where ρ is the density of air and swirls at speed v. So its kinetic energy is:

$$½ \; m_{air} v^2 = ½ \, \rho \, Avtv^2$$

The symbol ρ denotes the density, and as known from physics:

$$\text{mass} = \text{density} \times \text{volume}$$

And the rate of generation of kinetic energy in swirling air is:

$$\frac{½ \; \rho Avtv^2}{\mathrm{t}} = ½ \, \rho Av^3$$

So the total rate of energy consumption of the car is:

Power going into brakes + Power going into swirling air

$$= ½ \; m_c v^3/d \quad + \quad ½ \, \rho Av^3 \qquad \text{(A.2)}$$

Both forms of energy dissipation scale according to v^3. So the equation (A.2) predicts that a driver who halves his speed v makes his power consumption 8 times smaller. If the driver ends up driving the same total distance, the journey will take twice as long, but the total energy consumed by his journey will be four times smaller. Which of the two forms of energy dissipation – brakes or air-swirling – is larger depends on the ratio of:

$$(m_c/d) \, / \, (\rho A)$$

If this ratio is much bigger than 1, then more power is going into brakes. If it is smaller, more power is going into swirling air. Rearranging this ratio, it is bigger than 1 if:

$$m_c > \rho Ad$$

Now, Ad is the volume of the tube of air swept out from one stop sign to the next, and ρAd is the mass of that tube of air. This shows that the energy dissipation is dominated by kinetic energy being dumped into the brakes if the mass of the car is *bigger* than the mass of the tube of air from one stop sign to the next. The energy dissipation is dominated by making-air-swirl if the mass of the car is *smaller* (figure 5.6). To determine whether the energy consumption is braking-dominated or air swirling dominated, we compare the mass of the car with the mass of the tube of air between stop-signs.

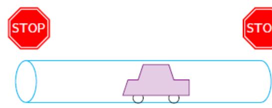


Figure 5.6: the volume of the tube depends on the front view of the car [13].

5.3 Reducing Car Energy Consumption

Let us now deduce the special distance $d*$ between stop signs, below which the dissipation is braking-dominated and above at which it is air-swirling dominated (also known as being drag-dominated). In general, the frontal area of the car with 2m wide and 1.5m high is:

$$A_{car} = 2\text{m} \times 1.5\text{m} = 3m^2$$

And the drag coefficient C_d is equal to 1/3, if the mass of the car is (X) kg, the special distance is:

$$d* = \frac{m_c}{\rho C_d A_{car}} = \frac{\text{x kg}}{1.3\ \text{kg}/m^3 \times 1/3 \times 3m^2} = (0.77\ \text{x})\ \text{m}.$$

And for X=1000 kg, the special distance is:

$$d* = \frac{m_c}{\rho C_d A_{car}} = \frac{1000\ \text{kg}}{1.3\ \text{kg}/m^3 \times 1/3 \times 3m^2} = 750\text{m}.$$

So, city-driving is dominated by kinetic energy and braking if the distance between stops is less than 750m for the car considered above. Under these conditions, energy can be reduced by reducing the mass of the car and choosing a car with regenerative brakes which roughly halve the energy lost in braking and driving more slowly.

When the stops are significantly more than 750m apart, energy dissipation is drag-dominated. In this case, the weight of the car does not matter. Energy dissipation will be approximately the same whether the car contains one person or six. In this case, energy dissipation can be reduced by reducing the car's drag coefficient and reducing the car's cross-sectional area, and of course, driving more slowly.

The actual energy consumption of the car will be the energy dissipation in equation (A.2), multiplied by a factor related to the inefficiency of the engine and the transmission. Typical petrol engines have an efficiency of about 25% [13]. This means that of the chemical energy that a car consumes, three quarters are wasted in making the car's engine and radiator hot, and just one 1/4 goes into useful energy:

$$\text{Total energy of car} \simeq 4\,[1/2\ m_c v^3/d \ + \ 1/2 \ \rho A v^3\ ] \qquad \text{(B.4)}$$

Let us now make this more concrete by using numbers for motorway driving. Let v = 70 miles per hour = 110 km/h = 31m/s and A = Cd Acar = $1m^2$. The energy consumed by the engine can be estimated to be roughly:

$$4 \times 1/2\ \rho\ \mathrm{A}v^3 = 2 \times 1.3\ \mathrm{kg}/m^3 \times 1m^2 \ \times (31\mathrm{m/s})^{3} = 80\ \mathrm{kW}.$$

If you drive the car at this speed for one hour every day, then you travel 110 km and use 80 kWh of energy per day. If you drove at half this speed for two hours per day instead, you would travel the same distance and use only 20 kWh of energy. This theory gives insight into how the energy consumed by your car could be reduced. The theory has a couple of limitations which will be explored shortly. A relevant question is if there is a possibility to design a car that consumes 100 times less energy and still goes at 70 mph. This is not possible if the car has the same shape. On the motorway, at 70 mph, the energy is going mainly into making air swirl. Changing the materials the car is made from makes no difference to that. An improvement to the fossil-fuel engine could perhaps boost its efficiency from 25% to 50%, bringing the energy consumption of a fossil-fuelled car down to roughly 40 kWh per 100 km. Electric vehicles have some wins: while the weight of the energy store, per useful kWh stored, is about 25 times bigger than that of petrol, the weight of an electric engine can be about 8 times smaller. And the energy chain in an electric car is much more efficient: electric motors can be 90% efficient.

5.4 Bergen City Case Study

In Bergen city, we want to identify the roads that cause the most loss in the car-energy. The work will be through two shapefiles, (a shapefile is a digital map that contains geographical data attached to the map as a table). The first shapefile [Fartsgrense_Hordaland] contains data for maximum speed limits for each road in Hordaland district, and the length of that road. The second shapefile [Trafikkmengde_Hordaland] contains data for the yearly traffic amount that occurs on that road, i.e., how many cars run on that road. We need to do a join operation between the two files (tables). The problem is that these two shapefiles do not have any shared field, like a primary key to do the join relationship between them or between the two attached tables. Furthermore, we need to have all the data in one shapefile to be able to do the required calculations for the car energy loss. For that reason, a spatial join method was used to achieve the join operation.

5.4.1 Spatial Join Relationship

This method joins attributes from one feature (layer) to another based on the spatial join relationship. The target feature [Fartsgrense_Hordaland shapefile] and the joined attributes from the join feature [Trafikkmengde_Hordaland shapefile] are written to the output feature class. After this operation is finished, we will have the attributes speed limits, road length, and yearly traffic amount in one place (layer) and then we can do the required calculations.

Before doing the spatial join, we have to do some data-cleaning operations. Some road segments in the table of [Trafikkmengde_Hordaland] came from the municipality of Bergen without any value for the traffic amount attribute. In this case, we will assign the minimum value we have to that road segment as a traffic amount which is 1500 cars per year. Some roads in our data set have no value for the speed limits. In this case, we assign them the lowest speed we have which is 20km/h.

Of course with these assignments or data, the results will not be 100 % correct. In general, obtaining 100% correct and complete is not easy. So we accept the results, especially, that the roads that we got and that do not have any values or their data are equal to "0" are secondary roads with low traffic amount as we have noticed from inspection at the visual map. After, the cleaning data operations and the special join is performed, we obtain the data we need in one shapefile, which is the maximum speed, length and the number of cars for each road. Now we can do the calculations using the formula (B.4) taking into consideration that the values for density of air ρ is 1.3 kg/m^3 and the cross-sectional area A=0.8 and the mass of the car m=1000 kg are fixed values:

Total power of car $\simeq$ 4[1/2 mcv^3/d $+$ 1/2 $\rho A v^3$]
Total power of car $\simeq$ 4 [(1/2 .1000 . $(Fartsgrense)^3/road\_length$) + (1/2 . 1,3 . 0,8 $(Fartsgrense)^3$)]
Total power ≃ [(2000$(Fartsgrense)^3/road_length$) + (2,08 $(Fartsgrense)^3$)] $\times$ [traffic amount]

Given that 1 kilowatt hour = 3 600 000 joules, and after converting the values from joules to kilowatt hour, values for column [Total power kwh] are illustrated in the Figure 5.7.

Shape_Leng	Speed_Limi	ÅDT_tota	Total Power	Total power Kwh
2	17	41000	201389360430	55941.5
1	22	5400	114323066268	31756.4
4.1	22	12200	63592105089.7	17664.5
9.3	17	43000	45904908338	12751.4
3.6	17	12500	34590218243.7	9608.4
4	17	13000	31936001415.7	8871.1
4.9	17	13000	26191981983.7	7275.6
2	17	5200	25569551741.5	7102.7
7.1	17	17300	23985529106.6	6662.6
4.6	14	20000	23728126391.7	6591.1
11.1	17	26500	23693654410.9	6581.6
4	17	9200	22792071848.4	6331.1
10.4	22	10700	22138574591.6	6149.6
5.3	14	20400	21143552394.4	5873.2
5.7	17	11800	20636554745.9	5732.4
6.1	22	5700	20188715420.1	5608
13.1	17	26500	20088811554.6	5580.2
6.3	14	21500	18797842711	5221.6
6.1	17	10500	17088987204.5	4746.9
13.4	22	10200	16399722922	4555.5
6.9	22	5000	15456466945.3	4293.5

0 (0 out of 74163 Selected)

Figure 5.7: An extract of the results of the total power in kWh of the cars for selected roads.

After the symbolizing of the obtained values in table 1 according to the total power field values, the highest four values are remarked with small red circles as shown in Figure 5.8. These values represent the road segments that cause the most loss in cars' energy. These road segments should be studied again to correct the design and to avoid this design when it comes to build new cities in the future.

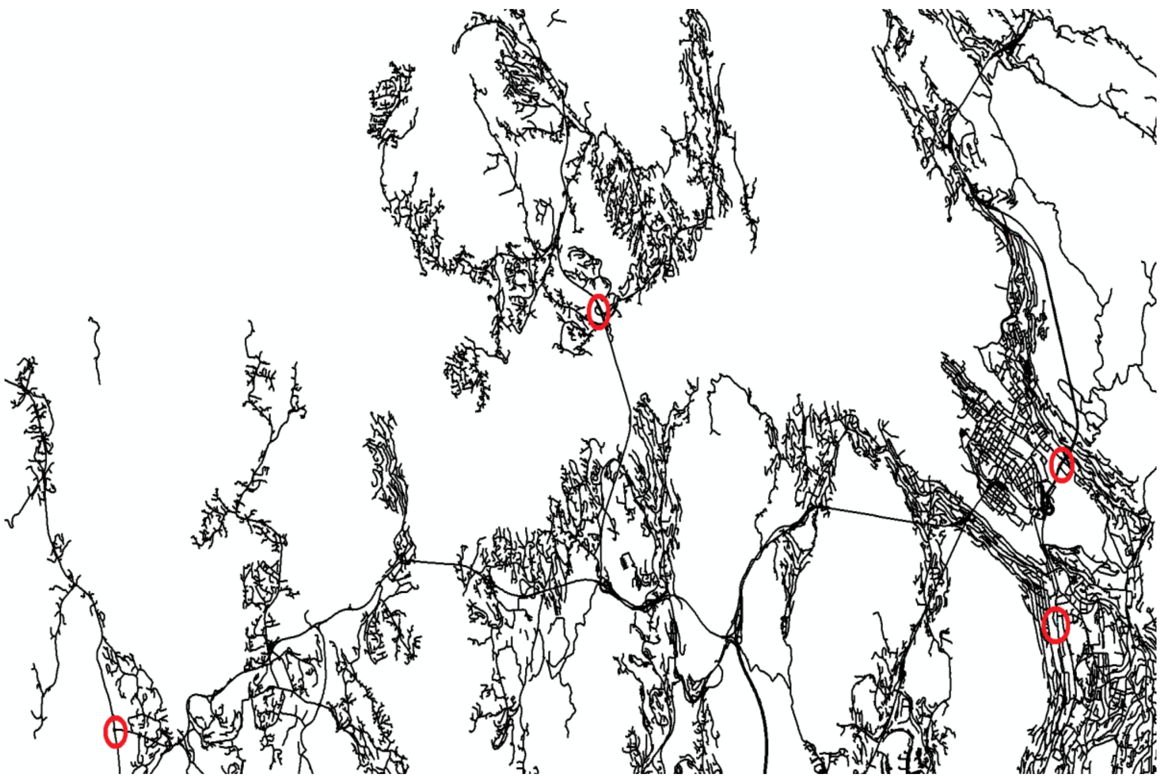


Figure 5.8: Four weakness points in the roads network design of the city of Bergen.

5.4.2 Discussion

The maximum value of the loss in cars energy across Bergen city is represented by the first line in the table 1, which is a road segment that has a speed limit value of 17m/s and the length of 2 km. 41,000 cars run over this segment yearly and uses cars energy equal to 55941.5 kWh. This segment is shown in Figure 5.9 as a red point.

Figure 5.9: The first maximum value of cars energy loss in the city of Bergen.

When zooming in to this road segment as the red circle shows in Figure 5.10, we can easily notice that there is a traffic lights on this road, of course we cannot say that the traffic lights is the reason of this loss, but in this case city planners and roads network designers have to give their opinion about the area and the road design, to lose this amount of cars' energy definitely means that there is something wrong in the design of the road.

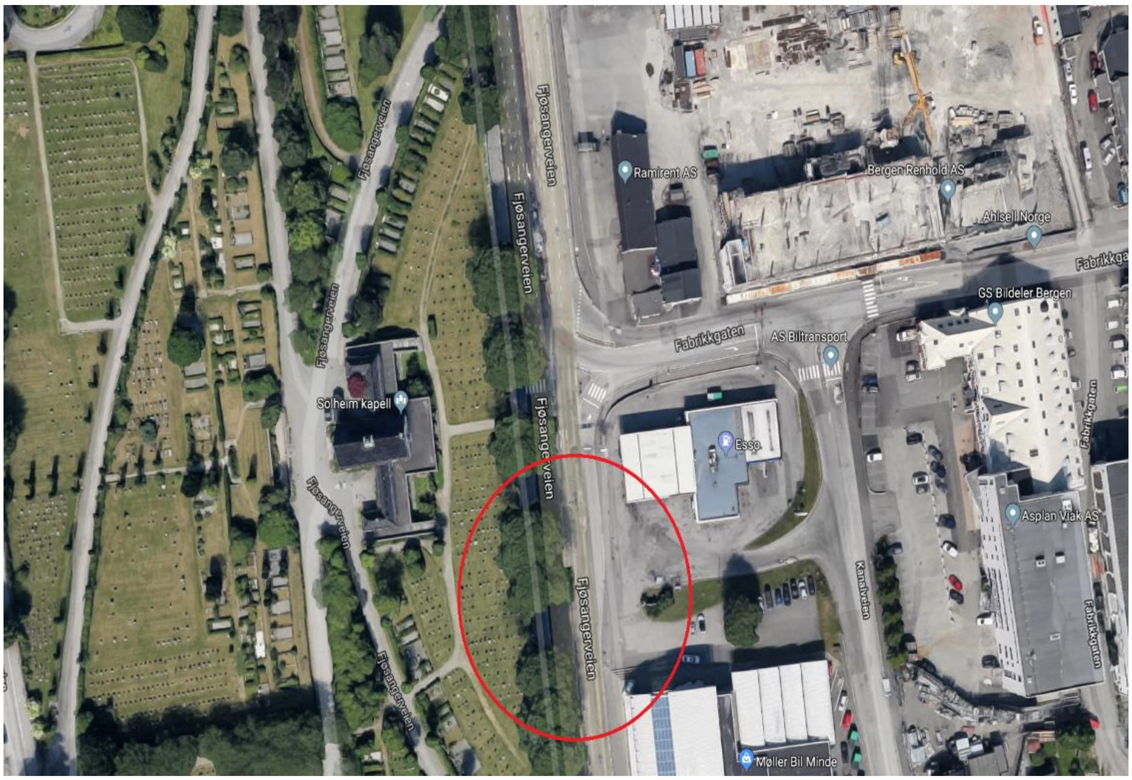


Figure 5.10: The first maximum value of cars energy loss in Bergen City displayed by google map application.

The second maximum value of the energy loss is represented by the second record in the table 1. This value represents a road segment that has a speed limit value of 22m/s and a length equal to 1 km. 5400 cars run over this segment yearly, this segment causes loss in cars' energy equal to 31756.4 kWh, this segment is shown in Figure 5.11 as a red point.

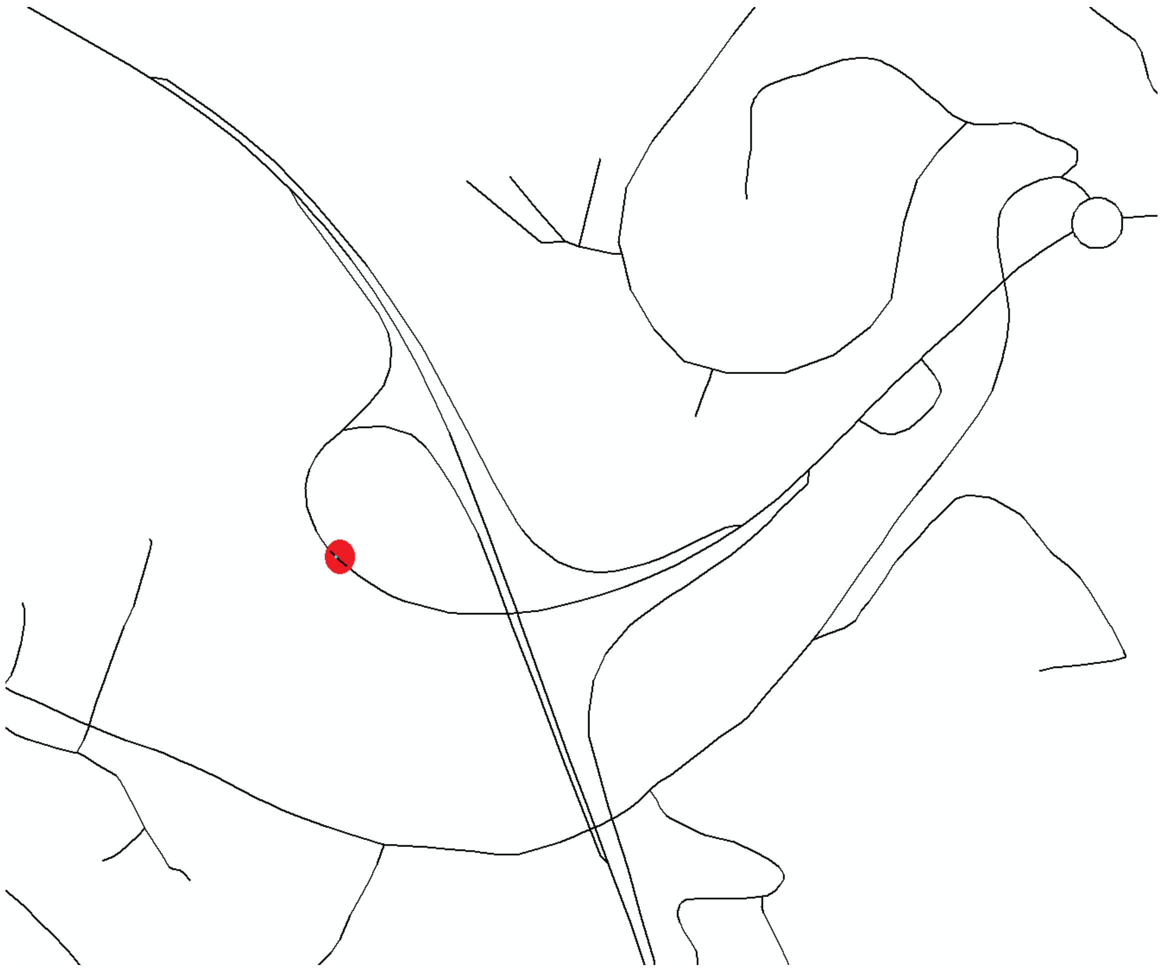


Figure 5.11: The second maximum value of cars energy loss in Bergen City.

When zooming in to the second result as the red circle shows in Figure 5.12, we can notice that there is a turn on this road, one solution to avoid this weakness design is to make the radius of this turn bigger.

Figure 5.12: The second maximum value of cars energy loss in Bergen City displayed by google map application.

Chapter 6

Conclusions and Future Work

Spaces are an important asset to our cities as they provide people with many opportunities to come together and engage with the community. The significance of spaces was the major topic that has been discussed in this study using GIS as the underlying computational engine to compute methods that can be used to evaluate the level of urbanity in any city.

6.1 Summary of Work Done

The space syntax theory has been applied to the city of Bergen. Within its three methods: the streets network design, the building density and topology type, and the MIX (the mixed-use index), we showed in this study how well or poorly a street is integrated with other street segments that form the streets network of the Bergen city. To calculate the integration degree between the streets, we have converted every street or every space to a line named segment or axial line. The work was performed by the aid of the *Depthmap* application that gives the ability to produce the axial map starting from the isovist map. We have used the four indicators: Global Integration (GI), Local Integration (LI), Metric Step Depth High Radius (MH), and Metric Step Depth Low Radius (ML) to calculate the integrated value for each street segment. Then we have classified these integrated values as high, medium and low values to be able to display them on the map as colors. For the second method in space syntax theory, building density and building type, we have used the spacematrix method within its two parameters floor space index (FSI) and the ground space index (GSI). Then as we did in the first method, we have classified the results as high, medium and low values for the same reason. The third method of space syntax theory, the Mixed-use Index (MXI), has been applied to the buildings layer of Bergen city, this method measures the functional mix based on the percentages of gross floor areas of dwellings, working places, and the commercial amenities places that occupy the floors of all urban blocks which form the city. Finally, the last step of space syntax theory is to overlay the three result values from these three methods to get the final result as high, medium, and low values representing the urbanity level of the studied city.

We have also shed the light in this study on the challenges faced by the car driver while driving. And calculated the energy consumed by cars depending on the kinetic energy of the car and the drag coefficient effect, while abstracting from the air resistance, the rolling resistance, and the energy that is needed by the car for heating the engine and the radiator. Drag coefficient effect is something that connected to the cross-sectional area of every car. We focused in our calculations of the consumed energy on only one factor from the four factors that cause the energy consumption, which is the enforcement of the speeding up and slowing down using the brakes by the driver. We have prepared the data for each road segment, the length of this segment, the speed limit on it, and the number of cars running on it yearly. The results that we have got show where the most energy consuming locations are on the road network of the city of Bergen. We have performed many operations with the aid of GIS to the raw data that was provided to us from the traffic department of the Bergen municipality. The results show that the most of this energy loss takes place at the traffic light signs or at the round aborts, and at the road intersections. Of course we still need the traffic lights, but we can cooperate with city planners to find helpful solutions that reduce the energy loss and can keep the traffic lights like building a bridge for example.

6.2 Future Work

Nowadays, a huge amount of geographical information has been produced and collected, especially from satellites and within the map digitization processes. After this data is transformed from the traditional form (maps on paper) into the digital form (digital maps), they can be stored in a computer system. Geographical Information Systems (GISs) are now widely used for this task, particularly, in designing and showing objects like city road networks, underground pipes, power lines. Expert systems and machine learning and data mining are well known intelligent techniques. Most of the researchers and decision makers rely on computers to analyze their data in deep which are stored in databases or files. However, databases or files are passive facilities. We can query or manipulate them only. They never actively tell us the knowledge deeply embedded or hidden in them.

Data mining is the process of employing one or more computer learning techniques to automatically analyze and extract knowledge from a data which resides in a huge databases. Its purpose is to show trends and patterns in data so researchers can extract useful hidden information from it.

The data mining and data warehousing technologies in GIS domain can automatically mine hidden knowledge and extract knowledge from raw data. If we can put this raw data in use with GIS, the hidden meanings or rules embedded in the environmental data which difficulty can be seen by default, can then be more deeply and precisely uncovered.

All the operations that have been used in this study have been designed as models by the aid of the model builder application and the built-in python scripting interface in the GIS software. By automating these models, we can do the analysis or data mining processes periodically in an efficient way in the future, all that we need is the new raw data of the traffic from the municipality. Furthermore, if we could make a full automated system that gets the traffic data automatically through sensors positioned on the road sides, and then count the cars number that run on each road segment, then analyze the data by a data mining system, and then produce useful readable information “knowledge” about the traffic movement, it will be a great work.

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