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Computational Tools applied to Urban Engineering

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1. Introduction

The objective of this chapter is to present some of the main computational tools applied to urban engineering, used in diverse tasks, such as: conception, simulation, analysis, monitoring and management of data.
In relation to the architectural and structural project, computational tools of CAD/CAE are frequently used. One of the most known and first software created to Personal Computers (PCs), with this purpose, was the AutoCAD by Autodesk. At first, the program offered 2D tools for design assisted by computer, presenting technical and normalisation resources. After that, the program started to offer 3D tools, becoming possible the conception and design of more detailed environments. The program is currently used for construction of virtual environments (or virtual scale models), being used together with other programs for simulation of movement and action inside of these environments.
Another software very used currently is the ArcGIS, created to perform the geoprocessing, in which tools and processes are used to generate derived datasets. Geographic information systems (GIS) include a great set of tools to process geographic information. This collection of tools is used to operate information, such as: datasets, attribute fields, and cartographic elements for printed maps. Geoprocessing is used in all phases of a GIS for data automation, compilation, and management, analysis and modelling of advanced cartography.
In addition to the programs of CAD and GIS, other interesting technology is related to Building Information Modelling (BIM), which represents the process of generating and managing building data during its life cycle using three-dimensional, real-time, dynamic building modelling software to decrease wasted time and resources in building design and construction. Some of the main software used for BIM are Autodesk Revit Architecture and Vico Constructor.
Computational tools for monitoring and management are very important for the urban development. Several urban systems, such as: transports, water and sewerage system, telecommunications and electric system, make use of these tools, controlling the processes related to each activity, as well as urban problems, as the pollution.

Therefore, in this chapter we will present details about these technologies, its programs and applications, what it will serve as introduction for the other works to take part in this book, many of which use such computational tools for study and solution of urban problems.

2. CAD (Computer-Aided Design)

It is a technology largely used in the conception of projects of Engineering and Architecture. It consists of a software directed to the technical drawing, with several computational tools. Amongst the areas in which the CAD is applied, we have the Urban Engineering.
Urban Engineering studies the problems of urban environments, emphasising the creation of planned environments to be sustainable, considering the balance of economic, territorial, and social factors. The infrastructure urban systems are subject of study, searching to optimise the planning of the environment, sanitation sectors, transports, urbanism, etc. In this context, we can observed the use of CAD programs to assist urban projects.
In respect of development of CAD software, we observe that without the postulates of the Euclidean Mathematics (350 B.C.) it would not be possible to create this computational tool.
Thousand of years later, more specifically at the beginning of the 60th decade of the 20th century, Ivan Sutherland developed, as thesis of PhD in the Massachusetts Institute of Technology (MIT), an innovative system of graphical edition called “Sketchpad”. In this system, the interaction of the user with the computer was perform by “Light pen”, a kind of pen that was used directly in the screen to carry through the drawing, together with a box of command buttons. It was possible to create and to edit 2D objects. Such system was a landmark in computer science and graphical modelling, considered the first CAD software.
In the beginning, the use of CAD software was restricted to companies of the aerospace sector and automobile assembly plants, as General Motors, due to the high cost of the computers demanded for the systems. Such software were not freely commercialised in the market. The Laboratory of Mathematics of MIT, currently called Department of Computer Science, was responsible for the main research and development of CAD software. In other places, as Europe, this type of activity was started. Other prominence developers were: Lockheed, with CADAM system, and McDonnell-Douglas, with CADD system.
From the 70th decade, CAD software had passed to be freely commercialised. The first 3D CAD software, CATIA - Computer Aided Three Dimensional Interactive Application, was developed in 1977 by French company Avions Marcel Dassault, that bought the Lockheed, revolutionising the market. The investments, as well as the profits, vertiginously grown. In the end of the decade, programs for solid modelling already existed, as, for example, the SynthaVision of the Mathematics Application Group, Inc. (MAGI).
From 1980, with the development of the first Personal Computer (PC), by IBM, the Autodesk released, in November 1982, the first program of CAD for PCs, the “AutoCAD Release 1”. In 1985, the Avions Marcel Dassault released the second version of CATIA. In this same decade, the workstations (microcomputers of great efficiency and high cost, destined to technical applications) were developed, using the operational system UNIX.
In the 90th decade, specifically in 1995, the SolidWorks company released the SolidWorks 95 3D CAD, revolutionising the market for used the operational system Windows NT, while the majority of the programs developed was destined to UNIX. In consequence of this, SolidWorks 95 demonstrated to be a software with good relation of cost-benefit, when compared with the competitors, excessively expensive.

In the following years to present time, the technology comes being improved and the software became very accessible around the world, with open access versions (freeware).
An important application of the 3D CAD programs is the creation of virtual environment, also known as electronic or virtual scale models (Fig. 1). Such application is largely used in architecture projects.

Fig. 1. Example of virtual scale model: *Hospital Metropolitano Norte*, Pernambuco, Brazil (http://acertodecontas.blog.br)

2.1 Working with CAD

As previously said, we had a great development of CAD software in the last decades. Amongst the main programs of CAD, the AutoCAD (http://www.autodesk.com.br) is distinguished. The software developed by Autodesk had its first version released in 1982, and recently, the Autodesk released the AutoCAD 2010.
The AutoCAD (Fig. 2) is a 2D and 3D modelling program with several applications, such as: mechanical, civil, electric, and urban engineering projects; architecture; industrial manufacture; and HVAC (heating, ventilation and air conditioning). It is important to notice that the AutoCAD is also largely used as tool in academic disciplines of technical drawing.

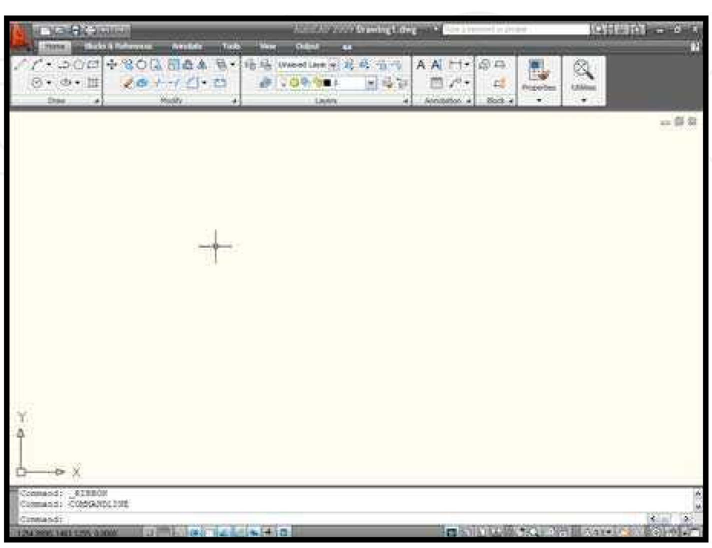

Fig. 2. Interface of AutoCAD software

AutoCAD have commands inserted by keyboard, making possible a practical creation of entities (elements of the drawing), at the moment of the conception of the desired model, optimising the work of the designer. Such commands substitute the necessity of navigation with the mouse to manipulate the toolbars.
The program generates diverse types of archive, which can be exported to other programs. Some examples: DWG (*.dwg); 3D DWF (*.dwf); Metafile (*wmf); Encapsulated (*.eps); and Bitmap (*.bmp). DWG archive is an extension shared for several CAD programs. AutoCAD is capable to import archives of the type 3D Studio (*.3ds), from Autodesk 3D Studio Max.
User of AutoCAD is able to associate with your projects, programs made by programming languages, such as: Visual Basic for Applications (VBA), Visual LISP e ObjectARX.
Another CAD software largely known is the SolidWorks (http://www.solidworks.com). Developed by SolidWorks company, from group Dassault Systèmes, is a 3D CAD program for solid modelling, generally used in the project of mechanical sets (Fig. 3).

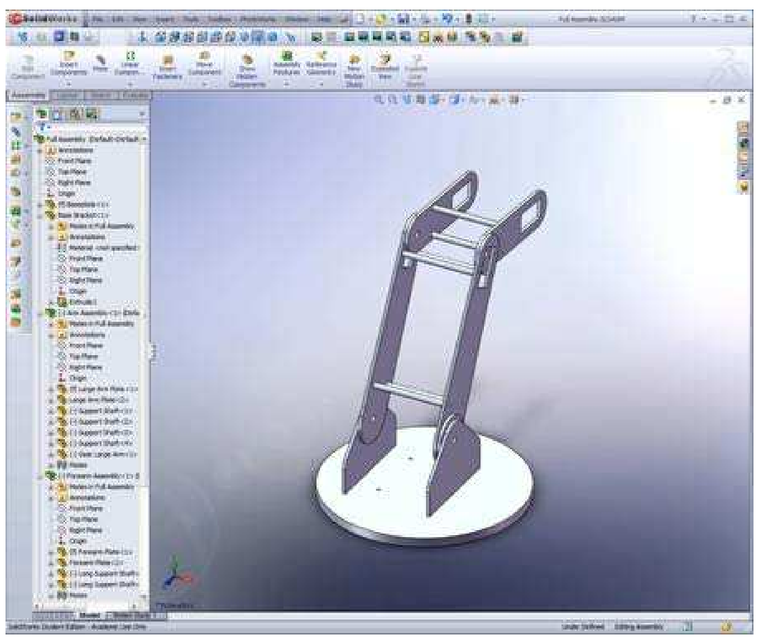

Fig. 3. Project in SolidWorks (http://www.danshope.com)

SolidWorks can also be used as CAE software (Computer-Aided Engineering), with simulation programs, such as: SolidWorks Simulation, and SolidWorks Flow Simulation.
SolidWorks Simulation is an important tool of analysis of tensions in projects. The program uses finite element methods (FEM), using virtual application of forces on the part.
SolidWorks Flow Simulation is a program of analysis of draining, based on the numerical method of the finite volumes. This program allows the professional to get reasonable performance in analysis of the project under real conditions.
SolidWorks is compatible with DWG files generated by AutoCAD, being able to modify 2D data or to convert into 3D data.
Other interesting CAD programs include: CATIA (Computer-Aided Three-dimensional Interactive Application), developed by Dassault Systèmes and commercialised by IBM (http://www.3ds.com), and Pro/ENGINEER, developed by Parametric Technology Corporation (http://www.ptc.com).

2.2 Application of CAD

CAD software have as main use the aid in projects of Civil Engineering and Architecture for urban environment, such as: buildings, roads, bridges, etc (Fig. 4).
CAD also is widely used in the project of transmission lines of electric energy. Such practice consists in optimise the allocation of transmission towers and wires, in accordance with the technical norms. An important characteristic is the topography of the land.

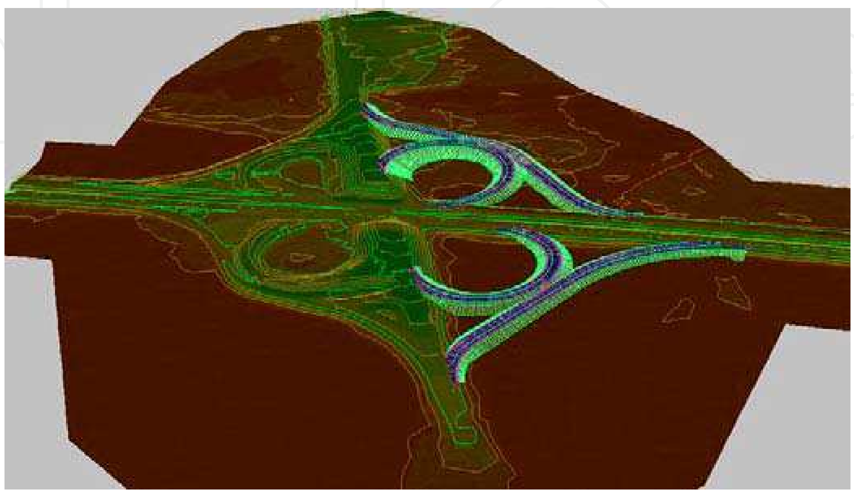

Fig. 4. Example of project of Civil Engineering - a highway (http://usa.autodesk.com)

Other applications in Urban Engineering include: the maintenance and update of sanitary networks, and the environmental recovery in urban areas. In the first case, CAD is used to update the database of the sewer network of the city, supplying detailed information. In the second case, CAD is used for mapping of a region, with the aid of a GPS system (Global Positioning System), identifying environmental delimitation (sources of rivers, roads, buildings, etc)(Mondardo et al., 2009).
There are several other applications of CAD in urban systems and areas related to Urban Engineering, and it is important to note, in practical terms, that CAD is nearly always associate to other technology: GIS (Geographic Information System), that it will be seen to follow.

3. GIS (Geographic Information System)

Engineering problems were on the last 40 years gradually directed to employ computerised solving techniques. Precision and increasing speed for calculating multi-variable operations are a good reason to use computational resources, but the quite unlimited possibilities to organize, simulate and compare data turned computer sciences on a strong allied for research and design activities.
The final claim to say that now we are living in an information systems age is the large accessibility of hardware and software, the diffusion of personal systems and all related facilities: servers, networks, telecommunications, etc.
An information system can be defined as an organised quiver of tools and data that can be used to answer on a systematic way questions structured by specialists. As these questions can be classified in patterns, it should be possible to build on artificial intelligence to make the system learn and deliberate by itself.

If the answer to a problem employs variables associated to geographic information, it's recommended the use a dataset structure to implement and model graphic objects that represents all on earth, natural or artificial. A Geographic Information System (GIS) is a set of tools that work with data presenting three basic concepts (Fig. 5): Geodatabase, Geovisualization and Geoprocessing (Harlow, 2005).

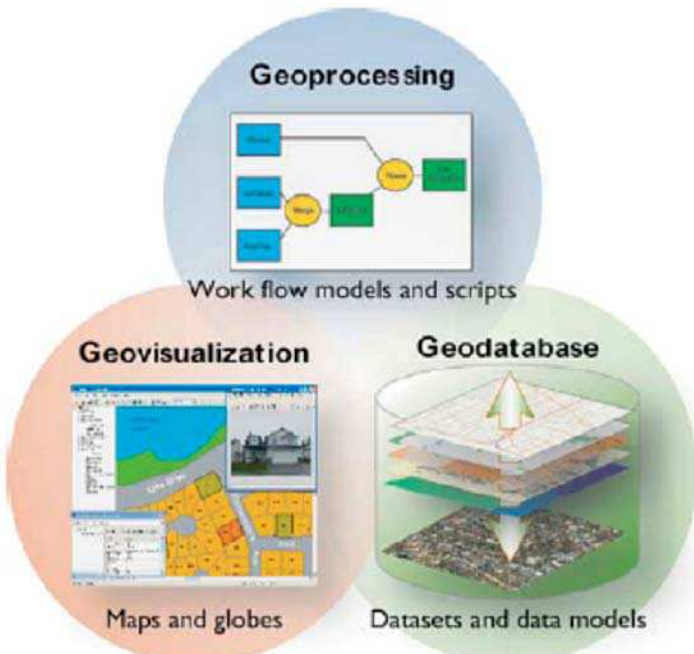

Fig. 5. Schema extracted from ArcGIS Reference manual showing the three views of GIS

Geodatabase represents the set of spatial data that can be expressed by rasters, vector features, networks, etc., and every rule to control their creation and management. Geovisualization is an action performed on spatial data by intelligent maps and views, from which we can view the database for querying, analysing and editing. Geoprocessing is the term used to designate operations on datasets that obtain outputs of analyses and generate new information.

Some engineering projects have territorial themes as industrial projects, social benefits, general infrastructure, logistics, demography, and other geo/urban/environmental aspects. On those cases the solution involves studying geographic elements and their available information, in order to perform technical analyses. So an information system for geographic data organisation, visualisation and processing will be appropriate to those problem solving. To be efficient as a GIS, the system must perform some general tasks: acquire, convert, organise and project the geographic elements; import, organise and extract imagery, numeric and textual information; process geographic elements and information with data integrity and operational efficiency; display appropriately the data and related operations (geoprocess techniques); perform simulations and comparison of alternatives; present support for program language and custom computational routines; generate new data based on selected results; publish maps and all sort of documents for project discussion; and permit data interchange with other systems.

As we can observe, GIS is designed to manage spatial data, and the geographic representation of this data can use many types of elements for plotting the information (Fig.

6): vector based features classes, as points, lines and polygons; raster datasets, as digital elevation models and imagery; networks, as roadways, pipelines, hydrology and other interlaced elements; survey measurements, as topographic annotation; and other kind of information, as postal codes, address, geographic place names, etc.

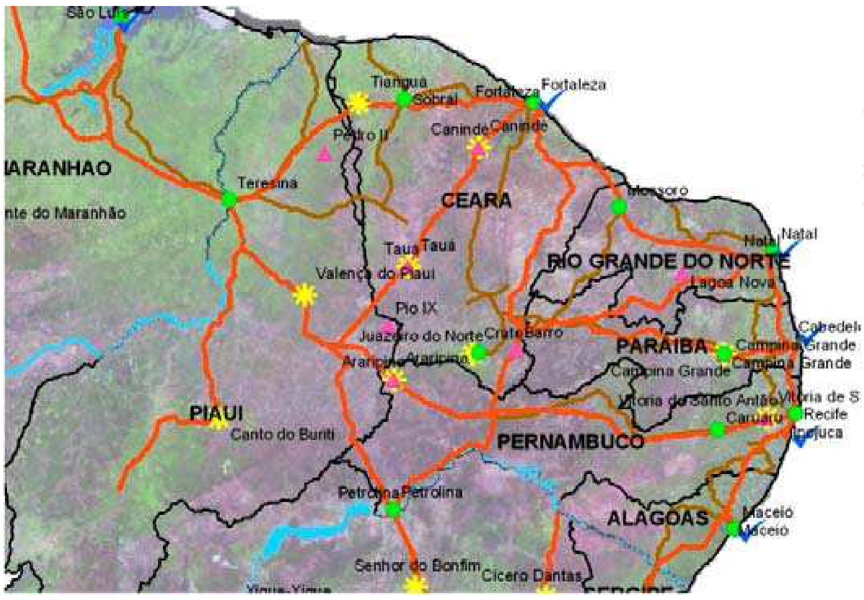

Fig. 6. Vector features overlays raster satellite image

These elements can be organised by layers, and could be selected by pointing or grouping for edition tasks or custom display. The selection methods could also be performed from spatial analyses or statistic classification. Georeferenced co-ordinates and related data tables of GIS elements help to improve these tasks.

Geographic data representation has integrity rules (Harlow, 2005), performed by spatial relationship patterns between elements, as topologies and networks. Topologies are used to manage boundaries behaviour, to apply data integrity rules, to define adjacency and connectivity properties, to structure creation and edition of new geometry, and to express other topological operations. They are used to represent area contours, parcels, administrative boundaries, etc. Networks are used to represent graphs and their connections, controlling paths, barriers and flows. They are used to represent behaviour of pipeline, transportation, traffic, etc.

Although organisation and management of spatial data can be well attempted with modern GIS programs, there is until an important aspect: how to deal with data quality. The cartographic databases can be generated from old charts or maps digitalisation, or from satellite and aerial imagery treatment. The numeric and textual databases must be converted into tables, and quite often comes from census and researches output. A great variability of data procedures can be observed world-wide when integrating data obtained from different fonts, places and scales. The periodicity of data actualisation is another deal to GIS users.

The problems don't result ever from confidence, trusted fonts may have different methodological approaches, and personal interpretation can also give different valid outputs. Professional development of GIS operators can help them to detect, evaluate and work that variability, and a methodological approach is needed to treat it suitable to each research task.

3.1 Working with GIS

Many users can be satisfied on using GIS as a dataset management tool for generating maps and classify data, but nowadays GIS is turning on a knowledge approach, where models incorporate advanced behaviour and integrity rules. The ultimate development on GIS procedures is directed to intelligent use of geoprocessing for built, explore and share the possibilities of geographic information. Users now are able to structure schemas and workflow models in order to improve their geoprocessing tasks, as import, check, integrate and compose data (Fig. 7).

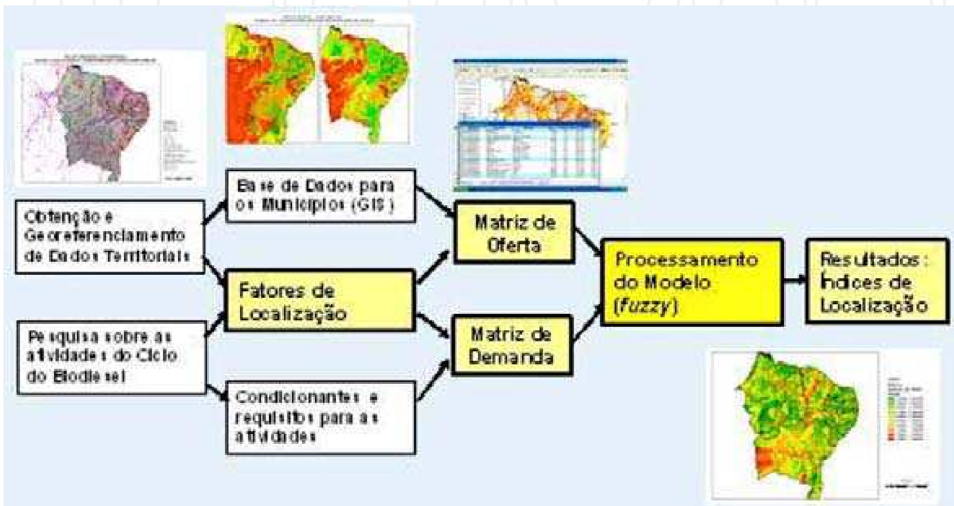

Fig. 7. Example of a workflow model for GIS based research on industrial location

As GIS is the best way to work data from local to global level, an efficient DBMS (Data Base Management System) is needed to perform data integration, actualisation, access and sharing. As result, GIS catalogue portals based on Web nodes are increasing in number and their interoperability is part of a concept called SDI (Spatial Data Infrastructure). Servers are used to host enterprise GIS and their databases, and to provide multi-user access. Geographic Databases are employed to control and develop published data, as maps, features and tables. They are known as Geodatabase, have a proper logic to work with datasets by applications and tools, and perform access and management tasks.

But GIS capabilities can also provide single users to customise their data. A Personal Geodatabase (PGDB) is example of option to collect and organise features and tables attempting to user needs, using desktop computers at low cost and with feasible results. If you are a adviser or researcher and are in charge of studying urban problems, you can go ahead on mounting your PGDB, however some steps must be observed.

The start point is to structure correctly your problem, identifying the factors and conditions that impacts on, a methodological approach to face it, and a technical procedure to get alternatives and produce results.

First, you must study what kind of information you need, identify the sources and think about layer and features organisation. Next, you must acquire geographic data from GIS portals or institutional sources. Many research and administrative institutions provide download of vector and raster data from their DBMS, or send it by request. If there is no available geographic data, it will be necessary to digitalis existing map and imagery, but for this task is recommended a professional with advanced knowledge of geodesics, cartography and geoprocessing.

After getting the appropriate geographic information is important to know that vector data is usually related to a table, which has a column whose contents link the graphic representation to a register. Raster image has pixel position attached to a co-ordinate value. Vector features as point, line or polygon has as code number for the system link requirements, but can also have a code for geographic cadastral purposes (Fig. 8). Geocode is a tendency on GIS procedures and has the advantage to make easy later joins and relates of table data with none geographic plot.

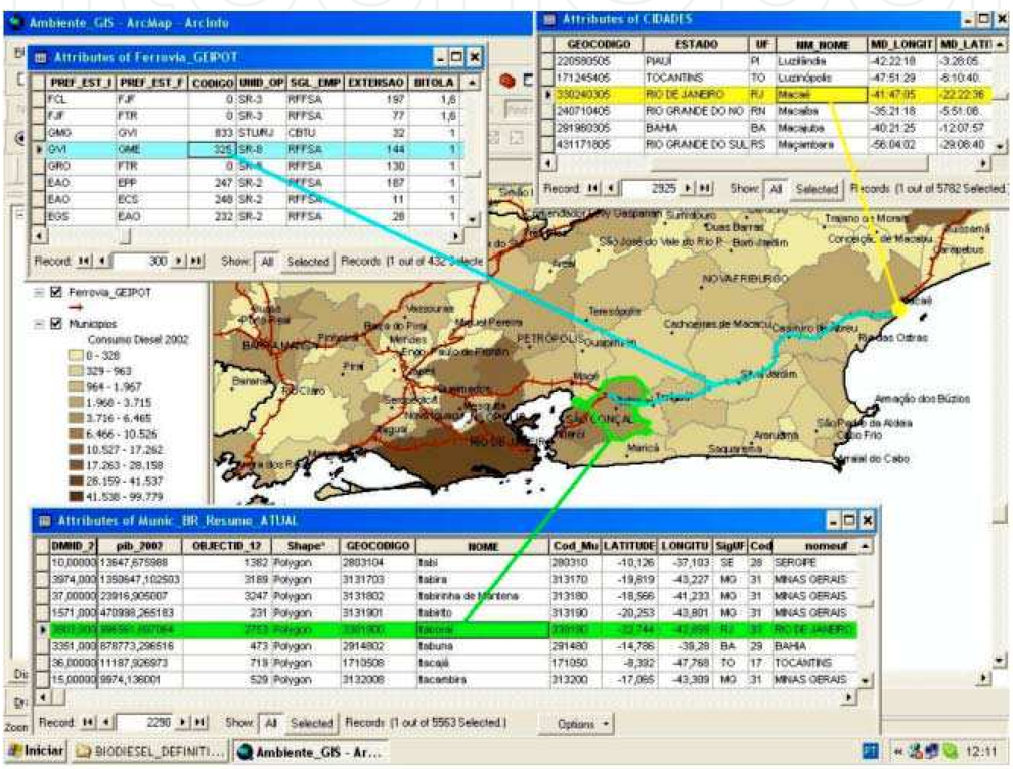

Fig. 8. Vector features as point, line and polygon with associated table containing geocode

In other words: if you get a basic data of shapes with related table presenting geocode column you can aggregate new data from other ordinary tables that has also this geocode column. GIS also enables visualisation of each element by selecting it from geocode, and permits editing the tables to insert new columns containing yours own information.

Second, you must organise your features and tables in a dataset, defining co-ordinate systems and importing independent features and tables to the PGDB. This modality of data organisation provides more security and flexibility, increasing edition and analysis tasks. Working with stand alone features can face restrictions that are not present on a PGDB structure, as it works more properly with layers, overlays, projections and co-ordinates.

Third, you must know what to do to improve your queries on GIS ambience. It is a lost of potential to use a GIS only for data visualisation or map creation, there is more than this. Both DBMS or PGDB can generate data performing spatial analysis or statistic classification. As you have the demands of your research well structured, GIS can help you to answer by crossing multi-layer information, selecting and editing data from SQL (Structured Query

Language) statements and processing new features containing partial and conclusive results.
Finally, you must obtain a valid output for your problem solving, and communicate it to others on a suitable way. GIS can help you on producing thematic maps, analytical graphs and technical reports. You can also get community, representatives and specialists to work in a participative mode using GIS to generate and validate output of decision sessions. Some people have difficulties to identify and interpret geographic elements, and GIS can highlight and detach text and visual information for making it easier.

3.2 Application of GIS

GIS technology is much used in Urban Engineering to analyse, in a detailed way, characteristics related to urban planning. In addition to CAD, GIS presents solutions for several problems, and it is applied, in a integrated way, in projects of Civil Engineering and Architecture, including the most diverse urban systems (Fig. 9), making possible the maintenance and update of service networks, as well as the environmental recovery in urban areas.

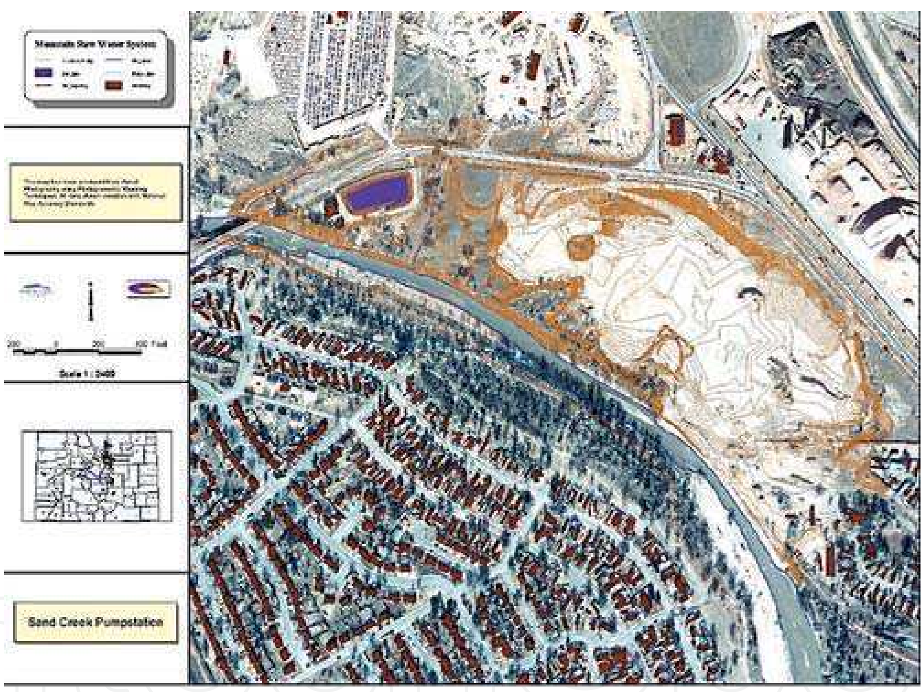

Fig. 9. Use of GIS in the mapping of water and sewer ducts (http://www.gis.com)

Nowadays, the accessibility of GIS technology stimulates educators to work in a new concept, called Geographical Inclusion, which can be performed on basic education class in order to provide young students with geographic visualisation and interpretative capabilities. We are living a age of saving resources, environmental care and sustainable actions, and GIS with his solving problem design and participative net work potential is the most strong partner in managing data for this purposes.
Concluding the technologies presented in this chapter, we will see to follow the BIM technology (Building Information Modelling), that it represents, in a certain way, an evolution of CAD technology, previously presented.

4. BIM (Building Information Modelling)

It is a technology that consists in the integration of all types of information related to conception and execution of a project of Civil Engineering. Such information, stored in efficient database, not say respect only to design or to modelling of plants and virtual environments, but also to management of execution time of project, geographic information, quantification of material used in all building, detailing of the constructive processes, sustainability, etc. In short, the technology makes possible that the work team has an integrated vision of the project. This allows, for example, that engineers and architects idealise and execute the project sharing the same base of information. This technology has been spread together with the practice of Urban Engineering.
In a certain way, BIM is seen as an evolution of 3D CAD techniques. In fact, this technology is defined as 4D CAD, where the fourth dimension is not physical, but the set of information that go beyond the engineering concepts, used in the development of the project.
The use of BIM can mean an effective optimisation of time and increase of the productivity levels. Other important characteristic is the easiness to perform modifications in the project, in any phase of execution. BIM makes possible the meeting of information, such as: the documentation of licensing for building, the established environmental conditions, and other legal aspects that are of extreme importance for execution of the project. Thus, the technology allows to greater efficiency in the taking of decisions during the elaboration of the project, easiness in the emission of building documents, establishment of deadlines, estimate of costs, information about the analysis of risks and management of the operational conditions of the installations.
Using a CAD software in an engineering project, the designer inserts detailed specifications through the headings, for example: specification of the material used in the confection of a wall, manufacturer of the material, necessary amount. In the case of BIM technology, such information is directly inserted in the drawing at the moment of the modelling.

4.1 Working with BIM

In BIM technology, a set of tools provided by one or more software is used for: modelling of surfaces; modelling and structural calculation; management of the building; manufacture management; environmental analysis; estimate of costs; and specification.
Autodesk Revit Architecture (usa.autodesk.com)(Fig. 10), is one of the main BIM software, having: tools of 2D and 3D drawing; co-ordinated database, in such way that alterations performed in the information are automatically update in all model, reducing the possibility of errors and/or omissions; associative sections of divisions table; libraries of details, that can be created and be adapted to the patterns of the project team; parametric components, that function as an open graphical system for design concern and shape creation; inventory of materials, that allows the calculation of detailed amounts of material, updating while the project evolves, on the basis of parametric alterations; etc.
There are other BIM programs by Autodesk, as Autodesk Navisworks (usa.autodesk.com), that it does not present tools of environment modelling, being destined to the revision of 3D projects or visualisation of models, that is the case of the freeware NavisWorks Freedom. The main tools include: aggregation of files and 3D data; revision tools; creation of 4D table; object animation; management of interference and detention/correction of conflicts in the project; exportation of DWF files (used in CAD programs); and navigation in real time.

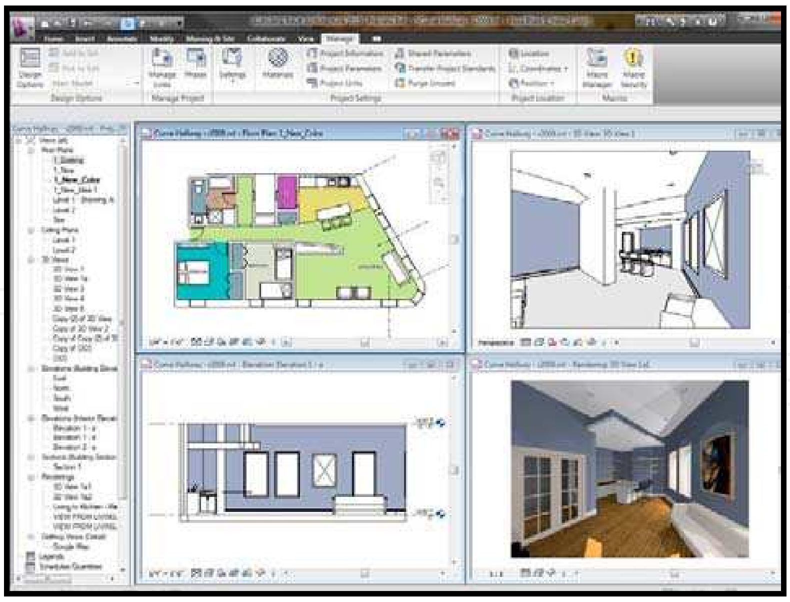

Fig. 10. Interface of Autodesk Revit Architecture (http://images.autodesk.com)

Other popular freeware is the Google SketchUp (http://sketchup.google.com)(Fig. 11), much used in the academic area, presenting modelling by means of surfaces. Such software presents limitations compared to the programs already cited. SketchUp works efficiently with information related to the localisation, size and design, reason for which is used in the confection of models that can be exported to programs, as for example, the Autodesk NavisWorks Review.

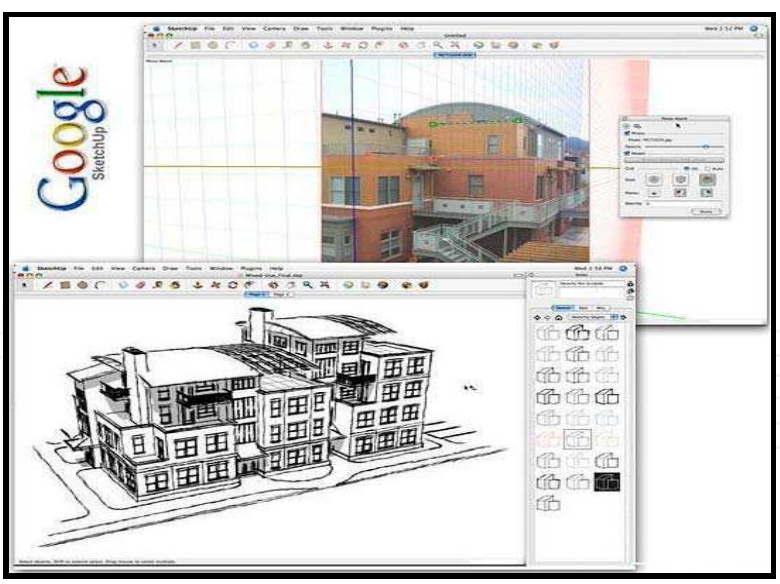

Fig. 11. Interface of Google SketchUp (http://www.crackvalley.com)

There are several other programs related to BIM technology, as for example, Vico Constructor (http://www.vicosoftware.com), presenting diverse characteristics and resources, such as: the structural analysis of the building; the constant update of the information, correcting possible errors of execution; the estimate of costs of the enterprise; etc.

4.2 Application of BIM

As well as CAD and GIS technologies, BIM presents a series of applications in the area of Urban Engineering, and currently it comes substituting CAD, in a effective way, because it presents advantages in relation to the management of the projects.
A current example of BIM application is the National Centre of Swimming of Pequim, China (en.beijing2008.cn/46/39/WaterCube.shtml). Seat of the competitions of swimming during the Olympic Games of 2008, known as Water Cube, the place have a useful area of 90,000 m², five Olympic swimming pools and capacity for 17,000 spectators, and BIM was used in all phases of the project (Fig. 12 and 13).

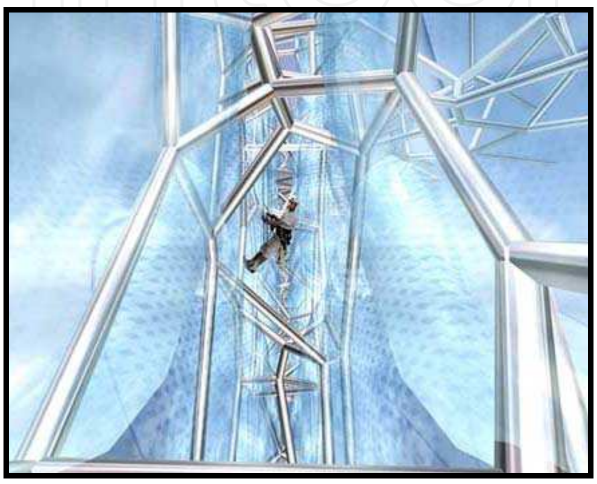
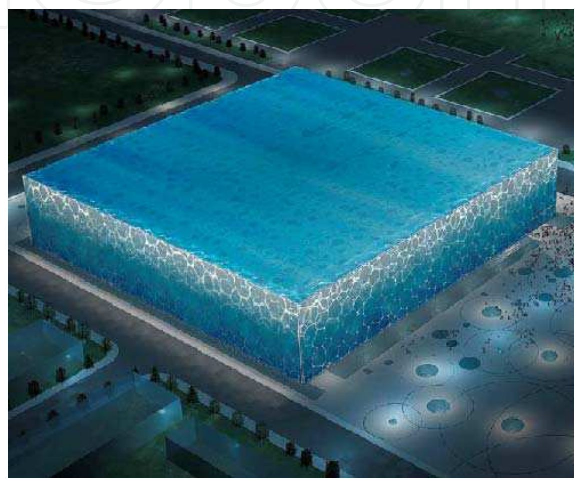

Fig. 12 and 13. Assembly of the structure of the Water Cube, and aerial photo of the place (http://comunicacaoexponencial.com.br)

Other example of BIM application is the International Airport Maynard Holbrook Jackson Jr., Atlanta, United States (Fig. 14). This airport is in construction phase with a stipulated deadline for 2011. In this project, of great magnitude, BIM is extremely necessary in the optimisation of execution time, since the old airport of Atlanta is overloaded. The estimated cost of the enterprise is approximately US$ 1.4 billion (Ford, 2009).

Fig. 14. Model of the Airport (http://bim.arch.gatech.edu)

5. Conclusion

This chapter looked for to present the main details on three technologies much used in Urban Engineering: CAD (Computer-Aided Design); GIS (Geographic Information System); and BIM (Building Information Modelling). As it can be seen, each one of them presents specific characteristics and with diverse applications in urban projects, providing better results in relation to the planning, management and maintenance of the systems.

In relation to presented software, it is important to note that the authors do not have any connections with the cited companies. The programs were shown only as computational tools that use the presented technologies, and there are many other commercial software and freeware that can be used in works involving CAD, GIS or BIM. Therefore, the work presented here does not represent any intention of marketing for no one of cited software and/or companies.

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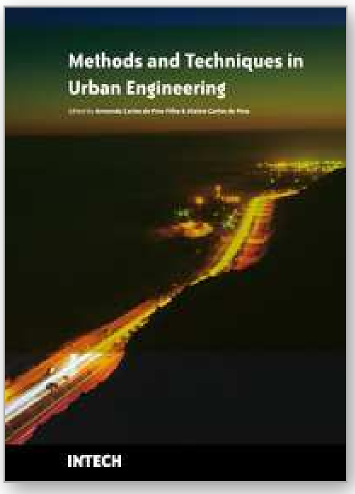

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A series of urban problems such as dwelling deficit, infrastructure problems, inefficient services, environmental pollution, etc. can be observed in many countries. Urban Engineering searches solutions for these problems using a conjoined system of planning, management and technology. A great deal of research is devoted to application of instruments, methodologies and tools for monitoring and acquisition of data, based on the factual experience and computational modeling. The objective of the book was to present works related to urban automation, geographic information systems (GIS), analysis, monitoring and management of urban noise, floods and transports, information technology applied to the cities, tools for urban simulation, social monitoring and control of urban policies, sustainability, etc., demonstrating methods and techniques applied in Urban Engineering. Considering all the interesting information presented, the book can offer some aid in creating new research, as well as incite the interest of people for this area of study, since Urban Engineering is fundamental for city development.