[DA-004] GIS&T and Civil Engineering

Abstract

Civil Engineering, which includes sub-disciplines such as environmental, geotechnical, structural, and water resource engineering, is increasingly dependent on the GIS&T for the planning, design, operation and management of civil engineering infrastructure systems. Typical tasks include the management of spatially referenced data sets, analytic modeling for making design decisions and estimating likely system behavior and impacts, and the visualization of systems for the decision-making process and garnering stakeholder support.

Keywords: construction, engineering, environment, transportation, water

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Explanation

1. Introduction

According to the American Society of Civil Engineers, civil engineers design, build, and maintain the foundation of our modern society (ASCE, 2017). Civil Engineering is a field of sub-disciplines and common specialization areas include environmental, geotechnical, structural, transportation, and water resource engineering. While not purely limited to infrastructure projects, the design and management of infrastructure such as bridges, roadways, water systems, buildings and wastewater treatment facilities are fundamental roles that civil engineers provide.

Civil Engineers have long been concerned with spatial data in the areas of surveying and engineering drafting, which are fundamental to the design of civil engineering projects. Technology advances have evolved these tasks into the fields of photogrammetry, satellite and laser imagery, and computer aided drafting and design. As civil engineering systems have become more complex, the reliance on spatial data for design and management of civil engineering facilities necessary to support human habitat is increasing. GIS&T provides methods for the visualization, analysis, and design for Civil Engineers in the management and understanding of spatial data relevant to the field.

2. GIS&T in the Civil Engineering Sub-Disciplines

The responsibility that civil engineers have varies greatly by sub-discipline and to understand the field it is necessary to first explore these sub-disciplines. The following sections provide broad overviews of some of the more typical analysis methods and tasks in five of the largest of the civil engineering sub-disciplines. Common among the sub-disciplines is the design and management of civil infrastructure systems to protect public safety and to support human habitat.

2.1 Environmental Engineering

Environmental engineering is concerned both for the proactive avoidance of environmental impacts and the mitigation of existing environmental concerns including those affecting air, soil, and water resources. Environmental engineering has a focus on sustainable practices for the planning, design, construction, and operation of infrastructure. The estimation of the amount and risks associated with environmental hazards such as airborne particulates and gases, subsurface groundwater pollutants, and soil contamination involves the integration of large spatial data sets and analysis of complex spatial relationships that are well-suited for GIS&T.

2.2 Geotechnical Engineering

Geotechnical engineering uses the principles of rock and soil mechanics to provide insight in subsurface conditions to assess the soil's suitability as a supporting foundation for infrastructure such as buildings, retaining walls, roadways, and pipelines. GIS&T is utilized extensively for managing subsurface data from boring logs and geologic investigations to provide estimates on the estimated performance of subsurface materials under different loading conditions. Analysis of slope failure potential and design of slope stability measures are also geotechnical engineering tasks that utilize GIS&T to improve risk and performance estimates.

2.3 Structural Engineering

Structural engineers design infrastructure such as buildings and bridges to carry anticipated loads to ensure public safety and minimize failure risk under a range of likely conditions. Analysis of locations for the suitability of sites of different types of infrastructure is a common task where structural engineers utilize GIS&T. Managing and visualizing spatial data for design load inputs such as wind forces, snow levels, and seismic risks is another common task where GI&T is heavily used. Increasingly the use of Building Information Modeling or BIM is prevalent in the design, construction and management of buildings by combining the architecture, engineering, and construction fields in a single 3-D platform.

2.4 Transportation Engineering

Transportation engineering is responsible for the planning, design, operation and maintenance of transportation facilities necessary for the movement of people and goods including roadways, transit lines, and bicycle and pedestrian facilities. The term GIS-T is commonly used to refer to the interdisciplinary field of geographic information systems and transportation and broadly covers topics such as graph theory and network analysis for estimating flow through uncongested and congested networks, spatial analysis for determining the demand for various transportation modes, determining optimum facility location, and recognition of spatial patterns in transportation crashes.

2.5 Water Resource Engineering

Water resources engineering is concerned with planning, analysis, and design of natural and manmade systems to manage the quantity and quality of water necessary for human habitat. Typical tasks in this field commonly done using GIS & T include delineation and analysis of watersheds for the estimation of surface runoff and stream and river flow estimations, managing and analyzing underground pipeline infrastructure, prediction of groundwater behavior, and monitoring and analysis of surface water and groundwater pollutants.

3. Common Themes for Use of GIS&T in Civil Engineering

While there are considerable differences in the responsibilities of civil engineers across the sub-disciplines, there are also some common themes in how civil engineers use GIS&T.

3.1 Scale, Accuracy, and Spatial Reference Systems

The scale of Civil Engineering projects is typically described in terms of feet and miles (or meters and kilometers). For example, many infrastructure projects are less than a city block, while the flow of freight goods and the impacts of greenhouse gases require analyses at a larger regional or global scale. The required accuracy of data used by Civil Engineers also depends greatly on the application. Land surveys, which are commonly used as the basis for many civil engineering projects, require a positional precision of 0.07 feet (ALTA and NSPS, 2016). Other civil engineering tasks are much more forgiving and positional precision in terms of plus or minus feet or meters is acceptable.

Most infrastructure design and construction tasks in civil engineering assume a planar reference system given their relatively local scale, while other large scale analysis tasks require global referencing systems. Common locational referencing systems used by civil engineers in the United States are the Public Land Survey System (PLSS), State Plane Coordinate System (SPCS), and centerline based linear reference systems. The PLSS is a rectangular system that covers 30 of the U.S. states and divides the land into six square-mile townships, each containing 36 square mile sections (USGS, 2017). The State Plane Coordinate System (SPCS) is another flat grid reference system that divides the U.S. into over 100 smaller zones with different projection systems such that the errors between planar and geodetic differences are kept to an acceptable level (Stem, 1989). Many civil engineering projects also use centerline based reference systems, which may be part of a larger statewide or regional system or developed specifically for a new project.

Common examples of these types of systems are for describing waterways based on stream miles, roadway milepost referencing systems, and pipeline centerlines. The use of stationing convention is common for roadways in either the imperial (10+00) or the metric (10+000) units where the numbers to the left of the “+” system represent number of hundreds of feet from the starting station in the imperial system or kilometers in the metric system. Civil engineering projects that utilize these types of linear systems would provide information on how to link the centerline system used to other referencing systems such as the PLSS or the SPCS as well as the use of a polar system, typically lengths and bearings, to describe the linear system within the project boundaries.

3.2 Integration of Spatial Data among Different Platforms

As mentioned previously, civil engineering is closely related to the surveying field and many types of civil engineering projects rely on survey data as the basis for their designs. At the scale of most civil engineering projects, surveying data is often stored and managed in computer aided drafting/design software (CAD), such as packages provided by the companies Autodesk and Bentley, as well as propriety software provided by the survey equipment manufacturers. Modern surveying techniques may utilize more advanced technology such as remote sensing techniques like photogrammetry, GPS and LiDAR, which generate large amounts of data. Pre-processing of this data into base mapping and digital terrain models of varying precision is typically done by survey professionals before use by the civil engineers.

The ability to pass data between various software environments is necessary since civil engineers will utilize countless tools for the design and analyses necessary to complete their tasks. Some tools are common across the disciplines, such as AutoCAD/Civil 3D and Microstation/Inroads, and others are highly specialized for each sub-discipline. Examples of discipline-specific software include models for analyzing the behavior of vehicles at a signalized intersection, estimating the amount of water from a storm event that will be infiltrated or will become surface water runoff, or the modeling the behavior of a structure during a seismic event. In many cases, after specialized analysis, the results will be passed back to other software platforms for more detailed design or visualization of results. GIS&T is proving to be a valuable tool in managing, merging, and analyzing spatial referenced data as it moves through the various stages during project planning, design, and management.

Structural design of building projects within the civil engineering often utilize a Building Information Modeling (BIM) platform for design with the most common software program begin Autodesk's Revit. Integrating BIM into GIS&T extends this further by providing insight into how the building structure fits within the broader built environment both visually and from a technical perspectives such as analyzing broader scale energy use or managing the health and safety of building occupants.

3.3 Analysis of Data Utilizing GIS&T

In an increasing amount of cases, civil engineering analyses of data is being performed directly within GIS&T platforms, as opposed to the discipline specific software platforms described in the previous section. These analyses are being done with both standard analysis tools within the GIS-platform and through specialized code design to run within a GIS-platform. By moving the analysis directly into the GIS&T environment, less steps are necessary in preparing data formats for import and export and the powerful tools for visualization and mapping of results with a GIS platform can be readily harnessed.

3.4 Visualization of Data

Civil engineering is a broad field, and, as mentioned previously, many civil engineers work within highly specialized sub-disciplines. When you consider the entire infrastructure system, there is a need for design teams involving many, if not all of the civil engineering areas. Consider a large roadway project or hydroelectric dam where there would also be a need to bring in expertise from multiple civil engineering sub-disciplines as well as other areas such as urban planning, landscape architecture, electrical engineering, and mechanical engineering. GIS&T is an important tool for reporting and visualizing input data and analysis results in a way that people from various technical backgrounds can readily understand.

In addition, civil engineering projects often involve many political and public stakeholders so conveying project design assumptions, objectives, proposed plans, and expected results to people with varying interests and backgrounds (both technical and non-technical) is extremely important for a project to be successful. In many cases, civil engineering projects cannot obtain required permits, public support and funding necessary for it to move forward without a broad understanding of its needs, costs, and impacts.

4. Research in GIS&T and Civil Engineering

Given the breadth of the civil engineering field and how valuable GIS&T has become in the field's sub-disciplines, there is a considerable amount of research being done in the nexus of these two fields. Current research can be categorized into three broad topics: use of new data sources and data integration, analysis methods, and visualization of data and stakeholder involvement.

The American Society of Civil Engineering is a major publisher of technical books, journals, and conference proceedings in the civil engineering field. Their online library search engine reported that over 500 book chapters, journal articles, and conference proceedings involving GIS&T were published last year, which is a similar number for the last five years (ASCE, 2017). Considering that each sub-discipline has numerous other journal publishers beyond ASCE journals, these results can be considered just a fraction of the published research that is occurring in the joint areas of civil engineering and GIS&T.

4.1 Data Integration

Civil engineering's growing use of GIS&T along with increased accessibility of digital, spatially referenced data sets has allowed for new data sources to be considered in the planning, design, operation, and maintenance of complex infrastructure systems. This category of civil engineering research involves how these data sources can be utilized to enhance or replace data in existing analytic tools or decision processes. The motivation behind research in this area comes both from improving the state of the practice in design and analysis and from improving efficiency by reducing time and costs necessary to perform these tasks.

4.2 Analysis Methods

Stemming from both the increased availability of data discussed in the previous section and from the availability of new analytic tools that spatial methods can provide, there is considerable research in how these can be used to improve the analytic methods utilized in civil engineering. Data mining utilizing GIS-platforms is also an area of research interest in many of the civil engineering fields since the spatial relationships within complex infrastructure systems is proving to be powerful and previously underutilized component to better understanding civil engineering system behavior.

4.3 Visualization of Results and Stakeholder Involvement

Civil engineering systems have broad impacts and many public and private sector parties have a significant stake in them. Many projects require public agency permitting, political backing, and public support to become realized. Navigating these processes is complex and time consuming and GIS-based visualization, public involvement, and decision-making research efforts are working to improve these processes to ensure that better decisions are made and to improve the efficiency of the decision process.

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