Urbanisation is driving investment in buildings and infrastructure

In the last 200 years urbanisation has occurred at an unprecedented rate representing the largest impact humans have had on the planet. This is spurring massive investment in infrastructure. The annual global construction spend is estimated to be $7-trillion, about 10% of world GDP. Of this transportation construction accounts for $1-trillion, utilities $2-trillion, and buildings $2.5-trillion. It has been estimated that between 2013 and 2030 $57-trillion in infrastructure investment will be required simply to keep up with projected global GDP growth. This includes investment required for transport (road, rail, ports, airports), power, water, and telecommunications. This is nearly 60% more than the $36-trillion spent globally on infrastructure over the past 18 years.

Buildings use about 40% of global energy, 25% of global water, 40% of global resources, and they emit approximately one-third of global GHG emissions. Residential and commercial buildings consume approximately 60% of the world’s electricity. Faced with environmental issues many governments are mandating energy-conservation measures especially targeting near zero energy buildings, an industry that is projected to grow by 43% per annum to reach $690-billion by 2020.

But governments are devoting less of their limited funds to capital infrastructure projects and are looking to the private sector to fill the funding gap. McKinsey singled out poor construction productivity as an important factor in eroding returns on infrastructure and making infrastructure less attractive for private investment. The stage is set for a radical transformation of construction and the convergence of geospatial and building information modeling (BIM) is expected to play an important role in this transformation.

Geospatial

Global revenues from geospatial products and services is estimated to be $150 – $270-billion per annum, about 0.2% of global GDP, and this is expected to grow by and average 13% per year through 2016. In addition geospatial services provide indirect benefits to consumers. Consumer benefits of geospatial services include time savings, fuel savings, emergency response, education, and competition. For example, more efficient navigation, estimated to provide benefits of $22-billion/year and to save 1.1-billion hours of travel time/year and to reduce fuel demand by 3.5-billion litres of gasoline/year. The value that consumers ascribe to geospatial services is about $350 per year for the average US household.

About a decade ago Dave Sonnen, Global Analyst for Spatial Information at IDC, projected that the location-aware market for geospatial services would exceed the traditional GIS market in 2005/2006. The release of Google Earth in June 2005 transformed the geospatial services ecosystem. At the present in terms of number of users and number of deployed apps, location-aware technologies have blown past the traditional GIS space, probably by an order of magnitude or so.

Convergence of geospatial and building information modeling (BIM)

These trends are driving investment in technology. In construction the adoption of building information modeling (BIM) is a major trend that has accelerated in the last decade motivated by the need for sustainability and higher productivity. Over the past five years the processes and technologies of building information modeling (BIM) have been transforming the construction industry. First architects and to a lesser extent engineers, and now increasingly contractors are adopting BIM to reduce risk and increase margins. There are signs that owners are also realising benefits from BIM and that operations and maintenance which are responsible for about 80% of a building's lifetime cost may be the part of the lifecycle of a building where BIM provides the largest benefits. Typical applications where BIM has been applied include automating clash detection, quantity takeoff, and change propagation; reducing data redundancy; improving collaboration among design teams; construction scheduling; automating bill of materials and job costing; and using 3D visualisation to involve non-technical stakeholders in the design process.

Buildings, energy, transportation, and utilities are sectors that are realising a significant return on investment by integrating geospatial technology with these new engineering design and other technologies. Several years ago, in an award winning paper at a conference organised by Britain’s Association for Geographic Information (AGI), Ann Kemp, then head of GIS at Atkins Global, the design and engineering firm, asked the question “BIM isn’t geospatial – or is it?” and then argued that integration of geospatial and BIM was essential to address the challenges of the 21st century. Kemp wasn’t the first one to speak on this. The need to integrate geospatial and BIM has been gaining traction for some time now. For example, government mandated energy efficiency for buildings is a major driver of BIM/geospatial
convergence, but there are many other examples in transportation, utilities, and municipal infrastructure. The integration of geospatial not only addresses specific vertical industry problems, but also enables a more holistic approach to the major challenges of increased urbanisation.

**Transforming construction with BIM, geospatial and 3D**

In the construction world 3D modeling and model-based design which integrate BIM, GIS and survey, and laser-scanning (lidar) in a 3D visualisation environment are increasingly being used to reduce the risk of budget and schedule overruns. Parsons-Brinckerhoff, part of the large global construction firm Balfour Beatty, has been a leader in applying 3D modeling for design validation, clash detection, parametric modeling, and design visualisation during design and 4D modeling (time+3D), 5D (cost+time+3D) for construction scheduling during construction.

Construction firms in particular see tremendous advantages in 4D models that integrate engineering design and geospatial data and allow the construction team to virtually build the project so that they can check staging and construction sequencing, alternative traffic routing during construction, and site logistics virtually. 5D and higher dimensions allow them to add additional metrics including cost, resources, materials, and equipment.

Laser scanning (lidar) has become an integral part of the 3D construction process. For example, construction monitoring involves capturing construction progress as well as being able to automate the process of checking for divergence from design when contractors for a variety of reasons don't build what is designed. Laser scanning can also provide reliable as-builts. 2D as-builts, still legally required, are often unreliable and rarely consulted by anyone post-construction. lidar scans of a completed project can provide the reliability that 2D as-built sheet sets lack.

One of the most important advantages of combined engineering and geospatial datasets is improved communication and coordination between all project stakeholders, and especially with non-technical decision makers. Being able to see photorealistic visualisations of what the project is going to look like is much more effective in communicating with politicians and the public. For example, on highway projects, Parsons-Brinckerhoff uses gamong technology so that the public can drive the highway and even the detours required during construction in a virtual environment before construction begins so that they can experience the changes and be prepared for them before they actually happen.

Accurately geolocating underground resources is a worldwide challenge. According to national statistics, in the United States an underground utility line is hit on average every 60 seconds. In recent years municipalities and ministries and departments of transportation are recognising the cost of unreliable geolocation information about underground infrastructure. Several studies sponsored by government agencies and conducted by university researchers have estimated the return on investment in improving information about underground utilities to be as high as $21,00 per dollar invested.

**Managing critical infrastructure at airports**

Airports are like cities. They have all the infrastructure that cities have plus some. One of the major hazards of all construction activity is inadvertently hitting underground infrastructure. The challenge is made more difficult because it is an environment where even a minor accident carries the risk of serious consequences.

*Heathrow: Access to high quality location information about underground infrastructure*

Heathrow is the busiest airport in Europe with an average 181 000 passengers passing through it each day. Heathrow has 13 different types of infrastructure, some of which are unique to the airport environment. To provide some idea of the magnitude of the infrastructure at Heathrow, there are more than 45 000 man holes, 72 miles of high pressure fire water mains, 81 miles of aviation fuel pipelines, and power cables carry voltages ranging from 9 V up to 400 kV.

Because safety is Heathrow's first concern, data quality is a top priority. Reliable data about infrastructure especially location is required to respond effectively to an emergency. In addition providing information about the location of existing infrastructure to the more than a thousand contractors working at Heathrow at any given time is critical to avoid incidents where critical underground facilities are hit. In 2002, 40% of Heathrow's underground facilities were mapped to within half a metre. At last count 72% of the underground facilities are mapped at this level of accuracy.

One of the most important things that Heathrow has done is designing business processes to optimise data quality. For example, contractors at Heathrow are contractually obligated to progressively deliver geospatially accurate as-builts over the lifetime of construction projects. As-builts are not only required at the end of the project, but during the progress of construction, so that they can reviewed by BAA as work proceeds. Heathrow Map Live system provides a single, simple web-based tool based on an Oracle database that allows everyone within the business to query, including geospatial query, retrieve and view information including location about Heathrow's infrastructure.
At Heathrow statistics show that the proportion of events where underground facilities have been hit during excavation as a result of inaccurate location information decreased by a factor of 6x from 2002 to 2011, primarily as a result of improved access and higher quality location information about underground infrastructure.

**Electric power**

According to the most recent World Energy Outlook 2012 from the IEA, global energy demand will increase by over one-third between now and 2035. Global demand for electricity is expected to grow by over 70% by 2035, with over half of the increase coming from China and India. The IEA estimates that a massive investment of some $37-trillion in the world's energy supply system is needed during 2012 – 2035.

To meet the challenge of increasing economic output while decreasing emissions, energy efficiency is seen as key. Residential, commercial, and public buildings account for one-third of the globe's total final energy consumption. As a result improving the energy efficiency of buildings, both existing and new structures, has become a global priority for governments and power utilities. Geospatial technology is playing an important role in helping utilities and their consumers reduce both electric power consumption as well as peak load.

*Horizon utilities: Energy density analysis for energy conservation*

Horizon Utilities was required by the regulator to reduce peak demand in their service area by 5.6% and consumption by 4.9%. The mandated targets are aggressive and Horizon needed to target customers with the highest energy footprints. Horizon partnered with public organisations who provided them with detailed building, property, and demographic data which they integrated using a GIS to perform energy density mapping, which enabled Horizon to successfully target their marketing on the buildings with the highest energy footprints.

*3D energy: Improving energy efficiency of new buildings*

3D energy uses energy performance analysis to help architects and engineers to optimise energy usage of new buildings, often motivated by programs such as LEED certification. Starting with a simplified BIM model that contains the key elements of the building, the geographical location of the building and surrounding natural and man-made structures and the local environmental conditions, an energy performance analysis of the building involving thermal, lighting and airflow simulations to compute an estimate of how much energy the building will consume in a year and test different design options (insulation, glazing, natural daylight, wind simulation, and ventilation) to identify best passive solutions, compare low-carbon technologies, and draw conclusions on energy use, CO₂ emissions, occupant comfort, light levels, airflow, and LEED certification level. 3D energy has found that it is often possible to reduce annual energy consumption and power bills by 40%.

*AGSI: Smart grid management system for operations and analytics*

The volume of data generated by smart grid networks has been estimated to be 10,000 times greater than for our existing electrical networks, and much of the data is real-time. Managing large volumes of real-time data from sensors is simplified by integration with geospatial technology that allows real-time monitoring and decision making.

Burlington Hydro's (BHI) real-time, geospatially-enabled smart grid operations and management system, developed by AGSI, integrates with their existing enterprise systems and uses location to provide a common point of access to all their operational data. For example, BHI's transformer status monitoring dashboard not only shows a map of their service area with transformer loading in real-time in the form of a heat map, but also reports historical loading and estimates, based on the history of overloading on a specific transformer, how much the lifetime of the transformer had been shortened as a result of the overloading. It supports the reconfiguring of the grid in real time to reduce the load on overloaded transformers and redistribute it to others with available capacity.

**Modeling urban environments**

Over half of the world's 6-billion population lives in cities and this proportion is expected to increase as we move toward 9 billion by 2050. Cities around the world are beginning to realise the power that comes from the convergence of modern information technology including building information models (BIM), geospatial/GIS, intelligent (connected) network models for electric power, telecommunications, water and wastewater, transportation, and other infrastructure, real-time data management systems including “big data” technology, and 3D visualisation. The City of Las Vegas, the New South Wales Government in Australia, the Los Angeles Community College District and the Federal University of Minas Gerais and the City of Belo Horizonte in Brazil are among the early pioneers in developing intelligent city models.
Las Vegas city infrastructure model

One of the problems that is identified repeatedly by municipal governments and utilities, is hitting underground infrastructure during excavations.

To address this issue two years ago the city government initiated an intelligent 3D project to model one and half miles of Main Street in the older part of Las Vegas. The project was intended to model below and above ground facilities including roadways, utilities and telecommunications, as well as buildings. To ensure engineering accuracy the project also specified implementation of a new low distortion geospatial coordinate system to make it possible to support engineering grade accuracy for geolocating infrastructure. Buildings were modeled in several ways, including extruding a building footprint from a GIS, using building models from the Sketchup 3D Warehouse, laser scanning existing structures, and complete BIM models for newer buildings provided by architects.

The deliverables were a set of georeferenced 3D models of all the underground and above ground infrastructure and buildings for the one and a half mile corridor of Main Street in old Las Vegas. Engineering design and other data were combined with the city's geomagery, digital terrain models and other GIS data. In addition a mobile augmented reality application was developed for the iPad that allowed staff in the field to view underground facilities virtually under the actual roadway.

The benefits of being able to accurately locate existing underground infrastructure in 3D are immense. A major benefit that Las Vegas experienced as a result of developing the intelligent 3D city infrastructure model is increased safety because of the reduced risk of unexpectedly hitting underground utilities especially hazardous facilities like gas mains. Other benefits include automated clash detection to identify potential problems when planning, designing and constructing new underground infrastructure. Operating costs have been also reduced because of reduced truck rolls for cable/pipe locate operations. Overall the city has found that the 3D model approach provides more information per dollar invested. As a result the city is expanding the 3D modeling project to an area six times larger than the original project.

In addition the city government is implementing new by-laws and regulations to ensure that the geolocation of underground infrastructure as reported in as-builds is reliable. For example, the city has mandated that underground infrastructure construction projects must use open trench excavation, and that the infrastructure must be surveyed before the trench is covered. The city as the owner of the right of way is also putting in place regulations to ensure that the city controls where new infrastructure is placed.

The Las Vegas infrastructure model represents a classic example of the benefits of convergence, the integration of engineering design data including building information models (BIM), geospatial data including digital terrain models, high resolution photogrammetry, and point clouds derived from laser scanning, together with 3D visualisation technology. At the present time Las Vegas' 3D city infrastructure model is believed to be unique in North America.

Los Angeles Community College District

The LACCD is the largest community college district in the United States and serves more than 250 000 students annually at nine colleges. In 2004 it was decided to initiate a project to create 3D BIM models of all the buildings including interior power, water, mechanical, and lighting systems together with 2D models of underground infrastructure on the LACCD campuses. Existing structures were laser scanned and feature extraction was used to create BIM models from the point clouds. For new structures BIM models were provided by the architects designing the buildings.

The primary motivation for creating the model was sustainability, helping to design environmentally sound and sustainable additions to current and future campuses. But over time the goal of the model has gone beyond sustainability to target social equity.

One of the most important design decisions that was made very early on was that all data including BIM models were to be georeferenced and stored in an Oracle Spatial database. This approach enabled all the data to be served to various applications. Real world coordinates enable the models to be easily integrated with geospatial data from a variety of sources. To ensure a uniform representation of all the buildings across all of the campuses, standards were adopted wherever possible. They include Open Geospatial Consortium (OGC) standards, BuildingSmart's Industry Foundation Classes (IFC), the US Army CAD/GIS Center's Spatial Data Standards for Facilities, Infrastructure and Environment (SDSFIE) and Construction Operations Building Information Exchange (COBie).

The LACCD model has been used for a variety of purposes including visualisation, energy performance modeling, predictive maintenance of facilities inside and outside of buildings, and even brought into a gaming environment for safety and security training.
The most important takeaway from these examples is that intelligent modeling of urban environments is not only possible with existing technology, but is actually being done. The challenge is no longer the technology, but organisational and legal. How do we encourage and enable the organisations (200 of them in the case of Sydney) responsible for the source data, some of it sensitive, to contribute and maintain data in a shared municipal model. And just as importantly how do we manage access to the data so that privacy is protected and it gets to the people who are authorised to access it.

Conclusion

Construction, electric power, transportation and municipal infrastructure including buildings are important sectors of the world economy. Over the next two decades these sectors will see a massive infusion of investment, primarily motivated by economic development and environmental concerns. In addition, as governments find they have less and less money for capital infrastructure projects, a greater proportion of the investment in infrastructure will come from the private sector, which will drive an increased focus on productivity to improve returns on investment. This in turn is driving a transformation of the construction industry that is reflected in accelerating adoption of integrated BIM, geospatial, and 3D visualisation, geospatially-enabled data management, and vertical applications based on these technologies. The real-world examples from the transportation, utility and municipal infrastructure sectors included in this article show that this is not star wars, but is already feasible with existing technology.

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