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Advancing the Spatially Enabled Smart Campus, Position Papers

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Position Papers, 2013 Specialist Meeting— Advancing the Spatially Enabled Smart Campus

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Advancing the Spatially Enabled Smart Campus

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"The trial separation of bits and atoms is over." So says William J. Mitchell in his book *Me++: The Cyborg Self and the Networked City*. What's more, these bits and atoms are increasingly interconnected, as everything from cell phones to cars to sensor swarms are increasingly able to communicate with each other. These twin themes—the blurring of bits and atoms and the rapid growth of communication networks—are the underlying focus for a freshman seminar I will begin teaching next week: *#Cyborg_Geographies: Hybrid Places, Networked Natures and the Emerging Internet of Things*. In the class, students will engage with literature on sensor networks, the emerging "programmable world," social media, P2P, and the fundamental reconfigurations of geography that are shifting under our feet. From smart cities to big data, from wikileaks to drone warfare, from swarm intelligence to the singularity, and from Twitter to Tahrir Square, the class will grapple with the ways in which our past conceptions of space and place are inadequate for fully grasping the new spatiality of our contemporary age.

I have taught courses on geographic information systems at Warren Wilson College since 2003. In May of 2005, I was struck by an article in the New York Times titled "A Web of Sensors: Taking Earth's Pulse." The idea of sensor networks as a sort of "macroscope" that could measure the previously unmeasurable resonated with me. I immediately set out to discover ways in which sensor network data might help us map data that previously had not been mapped. In 2006, I co-wrote a grant application with the Director of an NGO in Panama who was managing a 1000-acre nature reserve there. We received a grant of \$100,000 to build a comprehensive GIS database for the nature reserve and to conduct research on the feasibility of setting up a wireless sensor network to collect data on temperature, humidity and photosynthetically active radiation around the main research station at the reserve. Soon after, in 2007, I came across the Sun SPOT (Small, Programmable Object Technology) from Sun Microsystems. Sun granted us approximately \$3,000 worth of Sun Spot motes and base stations to experiment with as the Panama project moved forward. At the time, we were the only small liberal arts school receiving such a grant from Sun.

The project energized a handful of my students at a level I had not previously seen at my institution. They stayed up late in the lab, learning the necessary java to make the Sun SPOTs communicate, to run on solar power, to take sensor readings, to record those readings in a database, and to visualize those readings on web mapping platforms such as Google Earth. One student earned a paid internship at Sun's headquarters in Silicon Valley to continue research on Sun SPOT sensor networks. The same student then traveled to Panama with me to test out the feasibility of operating the technology in the harsh conditions of a tropical rainforest.

We ran into many challenges in Panama, but we were able to successfully send sensor data from the reserve via satellite back to Sun. We turned much of our energy and attention to powering the sensors with solar panels, distributing motes in such a way that data would successfully hop across the network despite the dense foliage, and (most difficult) keeping insects and water out of the Sun SPOTs. The complications of keeping the network in deep sleep, waking synchronously, and collecting data proved to be difficult, particularly when some of the motes would inevitably be fried by water and/or ants. We turned to using Hobo dataloggers instead, as they were completely water and bug proof. But overall the project was useful and successful, as it launched the career of one student and gave us valuable information on how we might further proceed in research along these lines.

Current Interest in Smart Campus Technology at Warren Wilson College

The Panama project has ended, but my interest in sensor networks continues. I am currently working on using Arduino microcontrollers, SD card data loggers, sensors and Xbee radios to create low-cost sensor network nodes. I am also working with a small quadcopter drone with attached camera to collect frequent high-resolution aerial imagery of our campus. Two initiatives, in particular, are driving my current interest in the collection, analysis and visualization of sensor network data.

I. Sensor Network Data for Sustainability

Sustainability is one of the core values embedded in the mission of Warren Wilson College. Recently ranked fourth in Sierra's "Top Ten Coolest Schools" for its commitment to sustainability, Warren Wilson College is home to a working farm, forest and organic garden. Environmental Studies is our top major, and the College's EcoDorm has been featured in the New York Times. As the only liberal arts college in the nation with a national student body and an integrated work and service program required for all students, Warren Wilson College promotes a unique Triad education program.

Our current work on Arduino-based sensor networks focuses on the collection of data on our campus farm. It is hoped that by collecting data on soil moisture, temperature, humidity and more we can better manage the resources going into running a working farm. In addition to the potential benefits to our sustainability efforts, this work provides excellent educational opportunities for students wanting to integrate their academic work in GIS and computer science with the very physical work of managing our campus farm and forest.

II. Smart Structures—Embedding Sensor Networks in a New Academic Building

Our College is currently raising funds to build a state-of-the-art academic building for the Social Sciences. This building will be the new home for our geospatial technology laboratory and will serve as a showcase for cutting-edge technology on our campus. As such, I am proposing that we strive to create as "smart" a building as possible by embedding sensors throughout the structure and by integrating the building with its surrounding environment (including the campus farm mentioned above).

Our campus was one of the charter signatories on the Presidential Climate Commitment, and we have long been dedicated to reducing our carbon footprint. The new academic building can serve as a model for demonstrating how sensor technologies can assist in this effort. It will also serve as our campus “dashboard” for other sensors on campus, allowing us to actively embed sensor data collection, analysis and visualization into our academics. Further, the data collected by such networks will provide us with new avenues of analysis, as we are forced to find ways to manage big data with cloud computing and analysis tools like Hadoop.

While some may overlook the small liberal arts college when considering research on sensor networks and spatially enabled smart campuses, it seems that the interdisciplinarity, creativity and critical thinking that a liberal arts college provides could contribute to advancing such work. Warren Wilson’s commitment to sustainability, its integrated work and service programs, and its living laboratories of farm and forest make it an excellent place for experimenting with the emerging technologies of sensor networks. I sincerely hope to be able to participate in your specialist meeting in order to further the research being done on this front in general, and to further the specific projects on my home campus.

Advancing the Spatially Enabled Smart Campus

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Topic 1: Course articulation and curriculum pathways: a knowledge-based solution.

This discussion will examine the potential of using an ontology/domain knowledge base with a service-oriented architecture to better understand similarities and difference among courses (Figure 1 & also see www.gistbok.org). It could be used for assessment of single courses content or as an assessment tool for course articulation. Also discussed is the possibility of a concept-based approach to selecting a curriculum pathway.

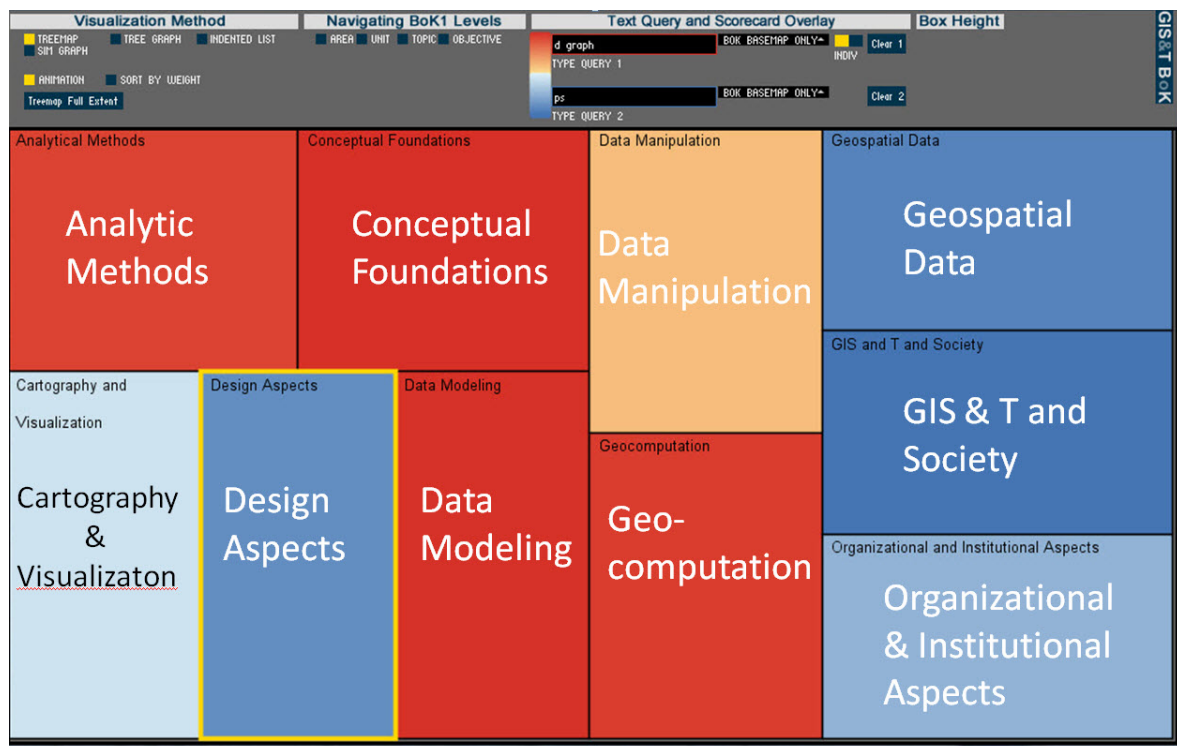


Figure 1: Comparison of an Intro GIS Course (Trending Dark Blue) and an Advanced GIS Course (trending Dark Red). Overlap is greatest for Data Manipulation (Tan). Analysis uses a Topic Model service and a visualization application to “project” each course onto the GIS&T BoK.

Topic 2: Spatially enabling research across the campus.

This discussion is focused on enabling the University research community to engage in interdisciplinary geo-spatial research. To accomplish this one needs: (1) a *common problem domain* that necessitates interdisciplinary research and collaboration, (2) an *ontology* that enables the community to “forge a common language” in a diverse and data-rich environment

and (3) a *computational framework* that fosters sharing, integration and synthesis of data for modeling, simulation and visualization of the problem domain.

The *idea* is to create a geographic and ontological nexus on which to build an interdisciplinary research community across the campus. The new framework will align the ontologies that span the different disciplines and use geography as the unifying platform on which the disciplines will interact. Its common domain will be the multiple spatial and temporal scales over which human activity occurs in the urban environment. “Organic” spatial units like a neighborhood, which can act as integrators for social welfare, quality of life, education, health and economics will be one of the scales of analysis of this approach.

The basis for this approach relates to the increase in the volume, velocity and variety of data that is now available to the social and behavioral science domains, much of which is geographic. This new data rich environment can be exploited by new methodologies of analysis and computing and new tools for structuring knowledge. However, to date, this transformation of approaches afforded by these new data and tools has yet to occur in the social and behavioral sciences. What these disciplines share is a common geography for their analysis, what they don't share is a common language. This has resulted in fragmentation of geographic data sets and analytic approaches, and a loss of synergism among the discipline.

To resolve these problems two things are needed: (1) an ontological approach to knowledge organization that bridges the conceptual framework of the different disciplines of social and behavioral sciences and (2) the utilization of geospatial technologies to create a common platform around which data sharing, modeling and analysis can occur. Some research questions that could be addressed include:

Data richness/big data: enablers of new approaches to domain research

- What is a neighborhood and how does place act as a mediator for social welfare, quality of life, education, health and economics?
- Can an “organic” delineation of a neighborhood be uncovered using an n-dimensional space of socio-economic data, education test scores, 311 complaint data ...etc. and how do these definitions compare with “named” neighborhoods? Can this analysis also be applied to higher level scales such as communities?

Ontology:

- interoperability between different scientific communities: how can we make sure the experts, each speaking the language of their respective community, understand each other (and each other's datasets) correctly?
- unexpected (re-) use of data: how can we propose new ways of combining and analyzing different datasets from our pool?

Geography and Geospatial system architecture:

- How do scientists in the social and behavioral domains think about the spatial/temporal aspects of their problems?
- What is the optimal design for the geospatial platform for enabling data-intensive collaboration among scientists in the social and behavioral domains?
- Can we create a network of research centers that share data and methodology and which fosters interdisciplinary research?

- Could this network also enable cross comparisons of different geographic regions with regard to the multiple spatial and temporal scales over which human activity occurs in the urban environment?

The goal is to create key elements of a framework for interdisciplinary research in the social and behavioral sciences through an ontology that bridges the communication between these domain sciences, a geospatial platform that create a common environment for data analysis, visualization and modeling, and the examination of these approaches in the context of a common shared problem domain, the urban environment and the issues of social welfare, quality of life, education, health and economics.

A pilot study “Spatial Laboratory for long term neighborhood research and community engagement” in New York, is underway that focuses on East Harlem. It will be used as an example of how this system might be configured (http://www.carsilab.org/spatial_lab/). The structure utilizes ArcGIS.com for organization of its spatial data.

Perspective on Advancing the Spatially Enabled Smart Campus

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University campuses are a perfect environment for experimenting with new technologies that enable people to navigate, manage assets/facilities, and perform cohesive research on a variety of subjects. The new technologies tend to revolve around smart phones and applications that provide various uses. In general, university populations contain technologically-savvy users who are willing to push the boundaries on experimentation with data and smart phone applications. The self-contained nature of the university provides many common themes that participants in a smart campus can focus on.

In my workplace, there is typically abundant need for development of smart campus data and applications, but precious little time and resources to devote to projects that aren't specifically related to capital development. As support for sustainable development increases among campus administrators, information/communication, volunteered geographic information, and sensor network technologies will become an important part of capital projects. A mechanism for integrating those components into the design development process must be supported by upper-level administrators, even if the cost may seem intangible to individual projects.

I would like to participate in this specialist meeting because I think it might help me assemble the justification for integrating innovative smart campus technologies into our workflow at the university. In particular, I think the sharing of best practices and existing examples might be helpful for my understanding of what is possible at my workplace.

I appreciate your time and consideration, and I look forward to learning and sharing at this meeting.

Growing a Smart Campus: Spatial Sustainability and the Living Learning Laboratory

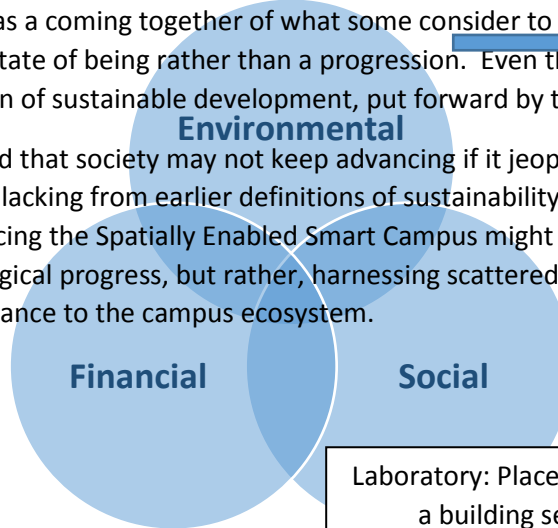
John Cook

Advancing *n.* from Advance *v.* -- to promote or help the progress, success, or completion of (something)¹

When the verb *advance* crosses the page, the initial thought is a pushing forward in a unilateral direction. ↑ Progress or moving out front immediately comes to mind. But when we discuss sustainability in a post 350 ppm era, we might perceive advancing differently; not as an outward unidirectional movement, but as a coming together of what some consider to be disparate movements/disciplines into a state of being rather than a progression. → Even the very capable, but somewhat ambiguous definition of sustainable development, put forward by the Brundtland

Commission in 1987, recognized that society may not keep advancing if it jeopardizes future societies' success.² What significantly is lacking from earlier definitions of sustainability is the ecosystem as organizing principle. So Advancing the Spatially Enabled Smart Campus might be read not as pushing forward an agenda or technological progress, but rather, harnessing scattered incidents into actionable moments that help to bring balance to the campus ecosystem.

Sustainability: "meet[ing] the needs of the present generation without compromising the ability of future generations to meet their own needs."



Laboratory: Place for Labor or Work – a building set apart for scientific experiments

Sustainability often falters on campuses, as it does in society, because it is implemented in a linear departmentalized sequencing rather than relying on its methodological foundation in systems thinking. What is often perceived as independent administrative and operational actions and procedures on a campus in support of its greater mission, are really interconnected practices that can inform and be informed by the academic endeavors of the institution, when realized as part of the greater system of research, education and community engagement. For example, a green office certification that invites various business units across the campus to evaluate their use of personal and campus resources in providing service to the university expands the dialogue between faculty, staff, student and community as participants begin to better understand their common relationship with the campus. The contact points of engagement are made more apparent through the self-examination and analysis generated from the green office certification. For instance a switch from printed hand-outs to providing QR codes for linking to online versions of documents at orientation for one department fostered greater dialogue between staff and students during orientation. The novelty of the QR codes and the slight increase of activity between the student and staff member took the passive act of picking up a packet of papers to actual discussions. Once the student accessed the online data another space opened up where the dialogue could continue between staff and students. Environmental Sustainability, conserving paper,

¹ "advancing, n.". OED Online. September 2013. Oxford University Press. 5 November 2013 <<http://www.oed.com/view/Entry/2889?rskey=4Bq8nh&result=1>>.

² The oft cited definition of Sustainability from the UN Report of the World Commission on Environment and Development: Our Common Future from 1987.

ink and energy by replacing hard copy handouts with a hyperlink led to an enhanced social engagement that further extended the participants recognition of the staff's role in fulfilling the academic mission of the university. The metrics generated from the "greening" of the department then becomes data for student and faculty research providing another feedback loop that further illuminates the staff's role in the campuses ecosystem.

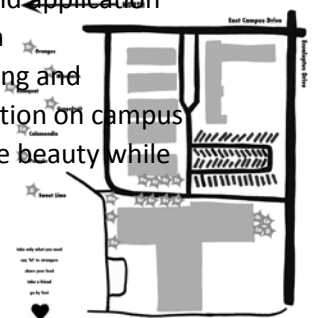
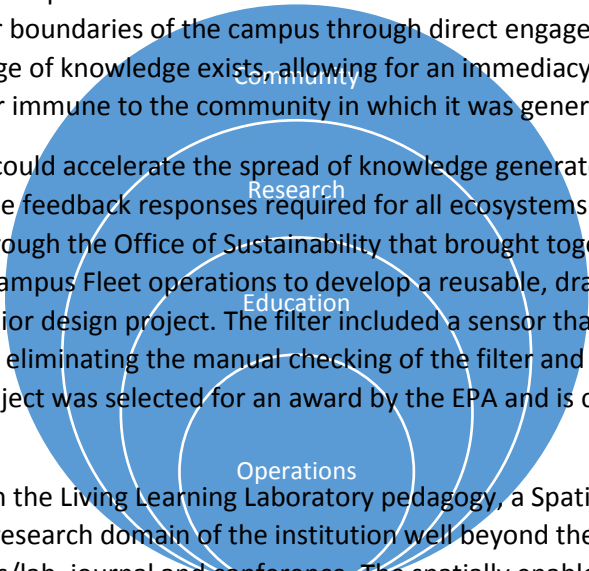
With multiple feedback loops, nodes of input and porous disciplinary boundaries systems thinking challenges the silo mentality of traditional academic, operational and social units at the institution. When Thinking in Systems, one thrives on the ebb and flow of data points in a continual process of adaptation and resilience. The Spatially Enabled Smart Campus provides one mechanism through which sustainability can map its organic transformation onto a campus.



The Living Learning Laboratory is space, place and time sensitive. Academic institutions have begun to recognize the advantages of using their campus as both locus and locale for advancing and sustaining the mission of the university. The campus, through the Living Learning Laboratory, enables research and learning that benefits all participants in an immediate and visible manner. The lab, classroom or lecture hall is exposed to the larger boundaries of the campus through direct engagement. In this space, a greater potential for seepage of knowledge exists, allowing for an immediacy of dissemination. A knowledge that is no longer immune to the community in which it was generated.

An enabled smart campus could accelerate the spread of knowledge generated on and through the campus while facilitating the feedback responses required for all ecosystems to thrive. Case in point was a project facilitated through the Office of Sustainability that brought together undergraduate engineering students and campus Fleet operations to develop a reusable, drain filter made from recycled materials for a senior design project. The filter included a sensor that indicated when the filter needed to be changed thus eliminating the manual checking of the filter and reducing potential of run-off contamination. The project was selected for an award by the EPA and is currently being developed for commercialization.

Further, in conjunction with the Living Learning Laboratory pedagogy, a Spatially Enable Smart Campus could extend the learning/research domain of the institution well beyond the confines of the formal academic structures of class/lab, journal and conference. The spatially enabled smart campus affords more opportunities for bits of knowledge to coalesce into organized data sets, artifacts if you will, that build a narrative for the campus. As these narratives weave together with existing metrics, they form an archeology of activity. As layers are added depth is added to breadth; our knowledge and application grow wider and deeper simultaneously. This can take shape in the form of consumption patterns of water and energy that denote shifts in research patterns. Or through recycling and compost bins that provide feedback on consumption patterns or direct users to information on campus metrics or resources on the value and end use of recycling. Or art exhibits that celebrate beauty while tracing the campuses history and directing its future engagement with the community.



What is a Spatial University

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In the past couple of years considerable interest has emerged about universities that foster a comprehensive approach to spatial teaching, research, services and infrastructure. For example, entities such as The Center for Spatial Studies at UC Santa Barbara, U Spatial at the University of Minnesota and NSF sponsored Spatial Intelligence and Learning Center headquartered at Temple University have received considerable media attention. This interest suggests that it is possible and desirable to define and identify a Spatial University. The objective of this presentation is to serve as a launching pad for a discussion about the appropriate criteria, methods of measurement, categorization and selection process for Spatial Universities. It advocates that such a designation would highlight exemplary universities that have successfully developed comprehensive programs that foster spatial approaches across a campus. From a public relations standpoint, Spatial Universities would serve as models that demonstrate the value to society for embracing a spatial perspective. Ideally, this designation would foster replication, encourage innovation and provide examples of best practices. The first step toward reaching a definition is the acceptance of criteria and metrics. To this end, the following dimensions are offered as a starting point for reaching a consensus:

1. Spatial thinking across the curriculum.
2. Geospatial workforce development.
3. Geographically oriented collaborative research.
4. GIS applications for campus administration and logistics

It is argued that elements of each of these dimensions should exist at a Spatial University with extensive integration occurring among many groups across the campus. Ideally, faculty and students should be working alongside staff and administrators using the campus and community as laboratories for novel, as well as, practical spatial applications and procedures. In the current computing environment this should include smart systems that use smart phones and other sensors to generate a real time pulse of the campus. Common activities existing at Spatial Universities could include (possible metrics):

- the maintenance of spatial inventories of a wide range of facilities and landscape features
- GIS based planning and logistical support
- innovative research projects using students as subjects in experiments
- internships that help prepare students for the workplace
- data base creation
- development of modeling and analytical procedures that enhance programs such as campus safety and access for disabled students

- creation of informative on line maps and visualizations that support navigation

Measures of success or the quality of the programs could include:

- operational administrative decision support systems
- utilization of online systems that improve way finding, movement, safety
- student placement measures
- smart systems that enhance the quality of life on campus
- creative teaching modules that incorporate spatial reasoning
- evidence of collaboration and sharing such as joint research proposals
- scholarly publications, presentations and even master's theses

It is also assumed that successful Spatial Universities are enabled by enlightened administrators and a proactive support staff. Therefore, it is valuable to identify successful organizational structures, funding mechanisms, computing infrastructures, incentives and technical support programs that promote synergism at Spatial Universities. As noted in the NRC report *Learning to Think Spatially*:

If we are to teach how to think spatially, then we need to provide both low- and high-tech support systems for practicing and performing spatial thinking significant individual and group differences in levels of performance

The same report provides a useful list of functions that a support system for thinking would provide:

1. Database construction and management: provides a capacity for data acquisition, entry, formatting, storage, and management (the functional equivalent of long-term memory)
2. Data analysis: performs operations and functions for data manipulation, analysis, interpretation, representation, and evaluation
3. Memory: provides working memory for tracking the flow of computations and the storage of working and final results (the functional equivalent of short-term memory)
4. Assistance: provides prompts, feedback, hints, and suggestions to guide the choice of data analysis steps and to manage the flow of work
5. Display: provides a flexible display system for the representation of working and final results to oneself and to others—in physical form (e.g., a graph on paper, a three-dimensional model of molecular structure) or in virtual form (e.g., on-screen, for hard-copy printing, for export to other software packages)

If a consensus can be reached that a Spatial Universities can be clearly defined and identified then it is important to establish a process that will add prestige to those universities that are selected. Such as discussion should focus on:

- What is the full range of dimensions?
- What are the appropriate metrics?
- What is a minimum set of criteria?
- What group should select?
- How should spatial universities be recognized?
- How should they be publicized?

- What is the proper role of associations such as the AAG, ASPRS, CaGIS and UCGIS?
- What is the proper role of commercial organizations?
- How can this become a global initiative?

Critically Assessing Big Data and its Sustainable Implementation in the Spatially Enabled Smart Campus

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Objective

The objective of this position paper is to identify critical factors in the conceptualization and implementation of “big data” in the spatially enabled smart campus. There is a critical need to understand how big data and its collection (e.g., with volunteered geographic information, VGI), distribution and sharing (i.e., cyber-infrastructure) can be undertaken in a fashion that improves human well-being (sustainability) in the spatially enabled smart campus.

The key factors in achieving this objective are to identify how big data can be implemented in a sustainable fashion, that is, how it can improve human well-being on the smart campus. Big data is a commonly proposed solution to a range of problems, including data-driven decision-making and pattern analysis, identifying and tracking diseases, analyzing social media such as Twitter (a billion tweets every 2.5 days)¹ or for enhancing national security.² At the same time, it may equally lead to undesirable outcomes such as geosurveillance and privacy invasions. This set of dual-outcomes lead Richards and King to identify three big data paradoxes:³

- The transparency paradox, where big data promises to make the world more transparent for problem solutions, while threatening the loss of privacy;
- The identity paradox, in which big data threatens to replace our right to self-identity with big-data-fed options (e.g., locationally driven goods and services);
- The power paradox, in which big data sensors are predominantly in the hands of state or corporate entities.

Guided by these paradoxes, we state that the sustainable spatially enabled campus must ensure that personal privacy is “baked in” to the campus design; that the smart campus should enroll our right to autonomy, especially concerning geolocationally available choices; and that those on campus have a stake in how geodata collected or contributed by them is gathered and shared.

To achieve these ends, we draw on the contributions of sustainability science to examine these paradoxes of privacy, autonomy, and power. There is now much interest in applying

¹ See <https://blog.twitter.com/2013/behind-the-numbers-how-to-understand-big-moments-on-twitter>

² Nakashima, E. and Warrick, J. 2013. For NSA Chief, Terrorist Threat Drives Passion to ‘Collect it all,’ Observers Say” *Washington Post*, July 14.

³ Richards, N.M. and King, J.H. 2013. Three Paradoxes of Big Data. *Stanford Law Review Online*, 66(41), 41–46.

insights from sustainability science to the smart campus—for example, the ninth annual conference on “Smart and Sustainable Campuses” will take place in Baltimore in April 2014. The Millennium Ecosystem Assessment (www.maweb.org) launched by the United Nations over a decade ago identified a framework for assessment of human well-being and the role of ecosystem services in sustaining that well-being. In other words, sustainability is that which is resilient to changes over the long term. If the smart campus is not sustainably designed (does not lead to improved human well-being in the long term) it will fail its objectives.

Significance and Applicability to the Smart Campus

The significance of this proposal is that it can enhance the application of big geodata to the smart campus by answering several key questions of the meeting: how do smart campuses contribute to sustainability; are there best (and worst) practice case studies of smart campuses; and a range of questions on how best to engage and empower students. What is not currently possible is to consensually identify proxies (ways to measure) for resilience in our three areas of big geodata concern (privacy, autonomy and power). We seek input from the workshop to develop and refine sustainability proxies for big geodata that can be applied to the smart campus.

In this proposal we use a case study to begin this proxy development process, and then to use the proxies to assess the recent expenditure of nearly \$5 million at the University of Kentucky to upgrade campus safety and security. This project includes the installation of nearly 2,000 cameras that can detect unexpected movement in order to send automated alerts, and identification cards that can track students, faculty and administrators entering buildings.⁴ To what extent were these systems implemented in ways that enrolled privacy, protected autonomy, and engaged students in the educational mission of the university? Do the technologies address identifiable needs of the campus (and surrounding neighborhoods), for example in traffic management or disability access?

Conclusion

In this proposal we draw from sustainability science to develop consensually agreed proxies that can critically assess the implementation of big geodata on the smart campus. Whereas big data is a commonly proffered solution to improve quality of life, it suffers from three contradictions that make it necessary to disambiguate sustainable from non-sustainable uses. Using better measures that resolve these contradictions, for example to resolve whether privacy has been enhanced or degraded by the smart campus, will ensure that human well-being is maintained (sustainable). We propose to apply these measures to case studies of big data usage on campus, beginning with a significant security investment at the University of Kentucky, but with the potential to extend from this use-case to other campuses.

⁴ See <http://www.kentucky.com/2013/08/29/2794114/university-of-kentucky-spending.html>

Smart Campus—My Experiences and Perspective

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As a founding director of FIU's GIS center, I applied the geo-spatial web to provide solutions to local communities. This is reflected in a number of urban, transportation planning as well as campus wide projects including the most recent "Mapping FIU's Faculty Residence" (see also: <http://maps.fiu.edu/fiufacultyresidence/>), a library Digital Signage, which includes an in-door navigation map and directory on touch screens, and a Library Resources Locator, which guide students to books, journals, and other resources in the library. I am the Principal Investigator (PI) of "Transportation Outreach Planner" (see also: <http://mpotransportationoutreachplanner.org/>), PI of a bicycle trip planning project (BiKE) (see also: <http://maps.fiu.edu/mpobike/>) and PI of a Walk to School Safe Route Planner (See also: <http://maps.fiu.edu/srts/>). We also developed mobile application for the BiKE project (<http://digir.fiu.edu/mpobike/Broward.html>). All of these projects were funded by perspective Metropolitan Planning Organizations (MPOs) of Palm Beach, Broward and Miami Dade Counties. These projects gave me insights of what some of the most urgent campus and community needs are and how geo-spatial web technology can provide solutions.

From my perspective, a smart campus is one that is efficient, intelligent, and environmentally sustainable. If geo-spatial solutions can be integrated with various campus information systems including student information, course catalog, course materials and syllabi, faculty research and publications, and library catalogs and research databases (e-books, and journals), it would greatly enhance its usability. The biggest challenge lies in the history of various existing information systems, which are not necessarily interoperable with each other. Integrating them in a single or a series of smart campus databases could be a very difficult task if not impossible. The solutions might lay in APIs and web services that can be published, or central indexed for retrieval.

Moving students around with efficiency and guiding them to locate campus resources can save both energy and students' time of navigation to campus and on campus. The following are low hanging fruits where geo-spatial solutions can play key roles and be integrated later to the Smart Campus solutions.

- 1) **A Multi-Modal Route Planner** (to Campus and on Campus): The route planner is most useful if multiple travel modes are included: Transit+Bike; Tranist+Walk; Bike+Walk; Bike Only. Google Route planner already includes Transit +Walk. However, on-campus navigation or route planner, along with integration of cycling are missing;
- 2) **Resource Locator and Navigator**_(all campus buildings, classrooms, library resources, and so on): Students needs to find where they can park their bikes, where they can find a

- vacant computer station or a study space, and where the classrooms are (typically at beginning of the semester). Most of the space and resource related information exist in either CAD files or facilities databases of the campus facilities management department. However, few campuses automated the facilities maps for public consumption.
- 3) **Volunteered Geographic Information (VGI) and Other Crowd-sourcing tools** can be best applied in areas of reporting infrastructural problems such as a road/path is flooded, campus security related issues, usability studies, and evaluations of Smart Campus applications;
 - 4) **Car-sharing programs for commuting students:** This is relatively easy to implement, as we only need addresses from students (privacy is a concern, and should be carefully implemented) and social networking tools. There are several vendor products and state or local government web services that serve this purpose.
 - 5) **Using GIS to map out student and faculty residence clusters:** Such mapping efforts can assist the administrators to make better decisions on where to place shuttle bus routes and stations.

A large aspect of Smart Campus solutions requires an intelligent academic information system. The emphasis is on the word "Intelligent." It shouldn't be only limited to browse, search, or discovery functions with query expansions. This system should be able to grieve "who the client is" and make intelligent recommendations accordingly. For instance, after basic demographic and academic interest and progress data is collected on a student, (s)he could enter the student ID, such a system should be able to recommend options of study area, relevant courses and professors, supporting services, technological and literary trainings and tutoring, and library research materials, etc., which cover all aspects of a student's academic life. This intelligent information system combined with spatial visualization tools, can then pin-point where some of these services and resources are available and route them there on a mobile device. Similar to what amazon.com presents to shoppers, this system should provide an exhaustive searchable listing of academic curriculum, services, technology, supporting structure, and with "map it" and "router planner" options.

Advancing the Spatially Enabled Smart Campus

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The term *Smart X* has been very popular recently, as in Smart City, Smart Bay, and now Smart Campus. All convey a similar meaning, but there are aspects of Smart Campus that give it special significance. In what follows I try to separate the generic from the specific. I also try to emphasize the questions and issues that arise when emphasis is placed on the geospatial: geospatial data, geospatial databases, and geospatial functionality.

We assume first that *X* fully exploits information technology. At some point in the future, when Smart Campus is fully implemented, mobile devices and sensors will be ubiquitous, and all will be connected through the Internet. Base mapping will be available, sourced perhaps from remote sensing or crowdsourcing, to resolutions and positional accuracies better than 1m. Base mapping will also be three-dimensional, such that 3D representations will be available of both the exterior and interior of all built structures and underground spaces. All individuals and vehicles will be constantly geolocated, through GPS, RFID, or other technologies, such that positions will be accurately known at all times, to better than 1m. *X* will also fully exploit the potential of the *Internet of Things*: significant features will exist as URLs, tagged with QR codes, and their attributes will be available for query. These assumptions are of course well beyond current reality, but well within our current vision of a spatially enabled society, and well within the capabilities of current technology.

One of the arguments behind this specialist meeting is that the university campus provides a unique laboratory with many advantages for exploring and evaluating the potential of Smart *X*. Substantial investments have already been made on most campuses in creating accurate representations of 3D built form, making university campuses among the spaces best equipped with base mapping. Some campuses have also undertaken extensive mapping of environmental features, such as trees and wetlands, in support of ecological restoration. Universities are also home to intelligent and highly motivated students, and GIS programs have long featured campus-based projects. Some universities have surveillance systems that can be used to gather spatio-temporal data on individual movements, and most campus faculty, students, and staff carry smart phones.

I believe it would be both wise and productive to follow a traditional sequence in our discussions. First, we need to identify the use cases of Smart Campus: what questions will people want to ask of Smart Campus? We need to bear in mind that our own abilities as a group to envision such uses are limited: that ultimately it will be the university's students who are best able to think outside the box, and that we should be discussing how to encourage and enable them to do so, rather than prescribing uses on our own. Second, we need to identify the data types that will be needed to serve these uses. This will require the identification of a Smart

Campus ontology, and given our limited ability to imagine a full set of uses it will be important that the ontology be extensible. Third, we need to identify the functionality that will be needed, and delivered perhaps as device-independent apps, many of them created as projects by students.

Within this framework, what do we not yet know how to do, and what other researchable issues arise? The following bullets provide my tentative thoughts in this direction:

- We do not yet know how to represent the interiors of built structures. There are many options, and they depend on use cases. BIM representations exist for many comparatively new buildings, but not older buildings. Applications such as evacuation or infrastructure maintenance have very different ontological requirements. Each ontology has its own issues with respect to data acquisition and maintenance.
- We do not yet know how to capture real-time position within built structures. There are several competing technologies, each with their own advantages and disadvantages in specific use cases.
- Real-time tracking of positions raises concerns about privacy. We will need to know how privacy concerns can be balanced against successful applications in each use case. The campus environment has longstanding traditions of information access, for example to individual grades, that will need to be taken into account.
- Besides practical applications, Smart Campus offers significant potential for social science, in terms both of discoveries made from observations of student behavior, to methods and techniques that can be tested on campus and then applied more generally. The latter include Big Data analytics, since the campus and its rich data can act as a convenient testbed for new tools.
- Many issues of concern to faculty, staff, and students are not confined to the limits of the campus, but also extend to the surrounding territory. Commuting and longer-distance travel, off-campus recreation, and off-campus housing are just some of the activities that may be aided by Smart Campus tools, if the geographic limits of the latter can be extended sufficiently. Similar requirements exist for Smart City. What are the associated requirements for data and functionality?
- We do not yet know how Smart Campus will scale. Will it be necessary to implement spatial divide-and-conquer, in order to achieve satisfactory scalability? Will peer-to-peer applications be feasible, or will all use cases have to be resolved centrally?

Advancing the Spatially Enabled Smart Campus

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I work with Esri's 84 international distributors to assist the 10000-plus universities around the world who use our software for teaching and research. Recently we started revisiting some of our key university users, to propose new thinking about how GIS is used on campus. In far too many institutions GIS software is hidden away in a few teaching laboratories, while at the same time the university shares many of the concerns as a small city—safety, public transportation, planning, facilities management, etc.—which could benefit from GIS application. Some 1,200 universities around the world are running an Esri University Site License, a form of Enterprise License Agreement, which allows unlimited software installations on desktop, server, cloud (ArcGIS Online), and mobile platforms. A growing collection of innovative universities are beginning to exercise these licenses to their full potential, creating a form of smart campus.

Smart Campus

Smart City projects are all the rage these days. Most are based on applying technology to improve energy efficiency, mobility, ease traffic congestion, and hopefully improve quality-of-life for citizens. The university can be considered an enterprise in a similar way than is a city. So why is it the case that many universities do not use their GIS as enterprise software? Why do individual professors struggle, often times, to secure funding for GIS software for teaching purposes, when it should be an enterprise-wide investment for administrative, research, and then teaching purposes? Other IT software and services, such as databases, IP telephony, hardware maintenance, or WIFI infrastructure, are funded that way. We use figure1, below, to remind university (and school district) administrators that the enterprise GIS should be theirs to own, and not only relegated to only a few geo-savvy professors teaching class.

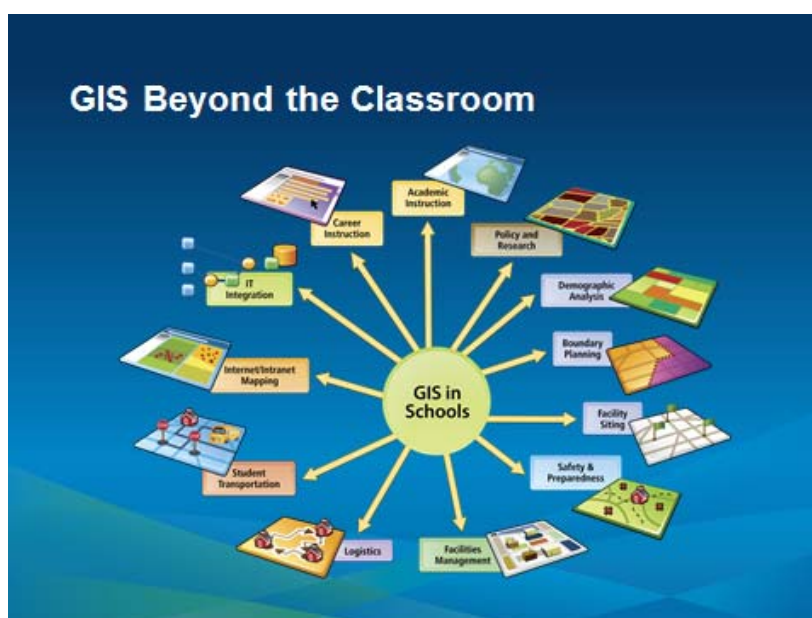


Figure 1. *Uses beyond the classroom, which include a wide range of administrative applications for GIS across the campus, school district, etc.*

GIS has demonstrated its capability to unite disparate data systems and themes, via the unique identifier that is geography, or the location of each entity being studied or monitored. Decision-makers need to see *where* they are wasting energy, *where* space is underutilized, *where* lawns are overwatered, etc. Decision-makers can gain access to this integrated information via what is called an Operational Dashboard (Figure 2). This vision of GIS is what is being implemented in countless organizations around the world, so it behooves universities to both teach and employ this enterprise implementation pattern as well.

Some of the attendees and speakers at this meeting will demonstrate progress being made in this sort of enterprise GIS or spatially enabled Smart Campus. Others will cover the intriguing area of knowledge representation, or in this context, “How might we make our campuses smarter?”. One of the key questions I hope we will answer is “What do we mean by smart campus, and which are its requirements as derived from students, faculty and administration?”. In addition to helping moderate the conversation I will be listening to suggestions and needs to bring back to Esri colleagues. Esri welcomes collaboration in improving solutions for smart campuses.



Figure 2. A sample *Operational Dashboard*, providing a synthetic view of the overall performance of a spatial jurisdiction: shopping mall, city, port complex or university campus.

Smart Campuses and Smart People

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At the heart of the idea of the spatially enabled smart campus is the idea of integrating spatial technologies with human spatial thinking to make people and campuses “smarter.” But technologies do not always make people smarter. In considering how to best implement a smart campus it is important to reflect on both positive and negative influences of technologies on spatial thinking and cognition more generally, in order to implement smart campuses in a way that truly makes people smarter.

Some lessons can be learned from research on GPS-based mobile navigation systems. These systems can have both positive and negative spatial thinking processes. Recent research has shown that navigation using GPS systems is not always more efficient than navigation using traditional paper maps (Ishikawa et al., 2008). That is, when using GPS navigation devices, people are less likely to develop an internal cognitive map of their environment, relying on their smart phone to provide the relevant spatial information. While one might conceptualize a person and his or her navigation system as a distributed-cognition smart system, this might cause problems in emergency situations, in which GPS navigational systems may not always be available. One challenge, therefore, is to develop spatial technologies that augment rather than replace spatial intelligence.

A second cognitive concern in the development of smart campuses is the possibility of information overload, as we use spatial technologies to track human movement, communication patterns, and resource consumption. While this will provide extremely valuable information, the challenge will be to provide “just-in-time” information to stakeholders, and not distract people with information that is irrelevant to their current goals. Attention is limited, and the distracting effects of even mobile phones are now well established (e.g., Strayer and Johnson, 2011). Critically this distraction happens with both hands-free and handheld devices, indicating that the interference is attentional, and not just about tying up one’s hands with different devices. One can imagine similar distraction effects if too much information is available on a smart campus map. For example, when navigating to Room 3512 Phelps Hall from across campus for the first time, someone might appreciate a map of the internal corridors of Phelps Hall, showing the location of this room. But most of the time, when walking across campus, this information would be superfluous and distracting. Providing access to the most relevant information at the relevant time will require both good models of the information needs of stakeholders in a smart campus, and good user interfaces to the relevant information.

A third cognitive concern is that there are well established individual differences in spatial intelligence (e.g., Hegarty et al., 2006). People differ enormously in their ability to learn the layout

of a new place, plan routes, or imagine spatial transformations. More critically, ability to use spatial interfaces is also related to spatial abilities, so that spatial technologies can often enhance the performance of those with good spatial ability while just adding to the challenges of those with poor spatial ability. The development of smart technologies also needs to take these individual differences into account.

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smartUJI: Integrating Information, Services, and Participation

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The University Jaume I (UJI) of Castellón (Spain) has recently adopted GIS technology in order to improve the monitoring and management of campus resources. The reasons for this adoption are: **(1)** budget cuts make it essential to efficiently manage the remainders what remains; **(2)** The managers of UJI are now computer scientist. The project, smartUJI, is based on the integration of university corporate data, digital maps and derivative applications (apps). This information system and its tools enable multiple views of the campus primarily for management purposes, but also offering services for other user profiles such as teachers, students and visitors. In addition, the project provides a focal point for multiple systems required to build a smart environment (energy, environment, mobility, participation).

The budget for the project is very low at the moment, but it is been boosted by several people considering it has a lot of potential benefits for everyone. The project team is mainly young computer scientists, with the support of architects and other technicians from UJI.

The project is mostly based on ESRI “templates.” We can take advantage of new features added by ESRI in the future, and our work and expertise can easily be applied to other campuses and environments.

The objectives of the project are to investigate and develop methodologies and technology to meet the following requirements:

- Avoid multiplicities in data, services and applications to save maintenance, space and dedicated staff;
- Enable the spatial analysis of the data from our environment to assist in making decisions;
- Publish and facilitate discovery and access to data, services and applications;
- Involve the university community in participation, information provision and resource maintenance;
- Provide opportunities for UJI research groups to gain experience with the “Smart Cities” technologies.

More specifically, the technical objectives to be achieved in this project are:

- Investigate methods and technology to integrate corporate information in a spatially based framework;
- Develop and integrate basic services (search, access, download, visualization) of the above information;
- Design intelligent maps supported by a spatial database which is structured, efficient and consistent;
- Create new applications addressing specific needs (spatiotemporal analysis of resource use, space management, routing, mobility) and take advantage of this way of representation and visualization;

- Enable role-based access to different levels of information and to create new content;
- Create a campus web portal to provide a unique access point to all this information and applications;
- Create mobile applications for the (voluntary) collection of in- situ data to detect behavioural patterns;
- Create mobile applications to improve resources consumption and mobility habits.

Campuses have a lot of graphic and alphanumeric information, which, potentially is of great interest for public use. The status of this information has several aspects to be improved, which motivate this project:

- Duplicity: can cause consistency problems.
- Integration: campus information is currently separated and not always in compatible formats.
- Accessibility: Many applications and services are already in-place, however they operate from separate platforms and are in many cases hard to find.
- Display: graphical representation on maps is easier to understand than tables and text reports.
- Analysis: The large amount of information available might be of great aid to assist in making decisions.
- Participation: The project offers the university community tools for providing feedback.

Description of the project

The first step in the creation of this spatial information system is modelling campus information and spaces to then build on top of this model, the tools as web services and applications. This information was provided by university central services in multiple formats, in many cases difficult to be integrated with other information available from our environment (weather, city streets, air quality . . .). Similarly, an important part of the campus applications and services were already in place and accessible through the corporate website, however they were working from independent platforms and in many cases, without easy accessibility. So it has been a very costly task to create the complete campus map from a variety of data sources.

The second step has been the connection of the project database (Local Government Data Model) with the University corporate database. The essential information has been imported from the UJI database to the project database and for the integration of both databases, several RESTful web services have been created to query the UJI database, looking for a trade-off between performance and maintainability. Also the sensitivity of the information is a big issue as the European data protection laws are very restrictive.

The third step has been the implementation of the infrastructure to support the system functionalities as:

- Creation of the multimodal routing network dataset, both outdoor and indoor
- Development of an indoor location system for all the university buildings
- Deployment of some new sensors such as video cameras and integration with existing sensors such as proximity and presence sensors or electronic locks. Other sensors as parking usage, filling level of dumpsters or soil moisture are planned to be installed in the future.

The fourth step has been the development of tools such as the People & Place finder, the Routing and Directions service, the Navigation service or the Service Request. Also other

applications are planned for the future as the Parking Assistant and applications based on Geofencing.

Figures 1 and 2 show the project web portal, based on ESRI campus basemap template, providing, among others, a mapping service for campus visualization and a place and person-finder service, which displays the contact information and space use, dimensions and description, and shows the best route to reach persons or offices. This alone represents a significant advance because many universities offer similar services based on static campus maps in PDF format and disconnected from the directory.

Other interesting applications are energy consumption monitoring, campus communication with the city through transportation networks, such as bicycles, apartment and hotel search according to their accessibility to services nearby, campus space reservation, and maintenance (work order) requests.



Figure 1: Campus basemaps

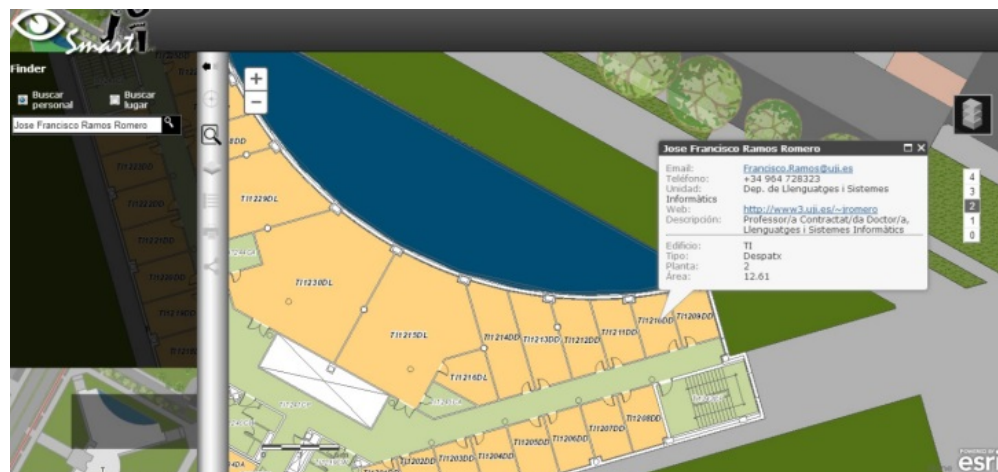


Figure 2: Place/People finder

The project will develop apps designed with gaming techniques in order to attract more users to participate in the provision of information and to educate the user on their habits.

Expected Benefits

The implementation of this project can be very beneficial for increasing visibility of the work and services offered by different research groups, departments and services of the University, enabling better knowledge sharing between the different stakeholders who are part of the university community, and increasing their commitment and involvement with campus life. More information, enriched by transversal contents, enables a real-time analysis that can improve resource management and decision-making to encourage a change in consumer habits such as commuting and ride-sharing.

With the establishment of a single access point to the different data, services and applications we reduced multiplicities and minimized inconsistencies, enabling real-time monitoring of the different types and sources of information that allow spatial analysis to highlight operational patterns and opportunities for improvement in the management of resources.

Another major advantage is that through greater openness and better visibility of the information, it encourages the university community in all its diversity, to participate and to be aware that their behaviour and contributions are useful for the proper operation of the Campus.

Industry Requirements for Smart Campus Infrastructure

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The views and opinions expressed here are my own and do not represent official company policy nor do they highlight any plans Apple may have now or in the future to support innovative campus map solutions.

The basic requirements of a campus map are typically accomplished with a wayfinding-based model (Roth et al., 2009). This approach is designed to help the campus community and visitors locate features and navigate on campus. A data model to accomplish these requirements is no different from any other base map consisting of roads, paths, buildings, parking areas, and other areas and points of interest. Nevertheless, standards are beneficial, particularly when college campuses desire accurate representation on commercial mobile map services.

Beyond base mapping, considering target audience characteristics helps us distinguish between requirements for inward and outward facing services that can be built to deploy rich content. Event feeds for arts, some lectures, and sporting events could be used to engage the general public, while the campus community may benefit more from the addition of real time spatially enabled class scheduling and on campus traffic patterns.

Deploying sensor networks across campus or employing citizens as sensors (Goodchild, 2007) invokes the need to protect privacy and safe guard the campus community from any unintended use of the campus data. A new proposal and a review of existing approaches described by (Gao et al., 2013) illustrates the research community's efforts to address privacy as it relates to trajectories and sensor networks. With this precaution in mind, what types of location-based services should be owned solely by campuses? Which ones should be developed by industry and private enterprise? Where can the stakeholders collaborate, and are we prepared to be innovative when accessible visualization of rich content can be cartographically difficult to accomplish?

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Advancing the Spatially Enabled Smart Campus

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Academic libraries have always been a breeding ground for new technologies. Some of the first large-scale computer networks were implemented in libraries. Pre-web technologies such as gopher and htelnet were designed to help navigate information resources such as online book catalogs and government-produced information. The presence of these networks made the library one of the few places where people other than scientists and engineers could access the Internet (interestingly, public libraries continue to provide vital Internet access to those unable to afford smartphones or broadband access at home).

Moreover, before electronic journals and broadband became ubiquitous, the library was perhaps the only place on campus where faculty from radically different disciplines would meet in the course of doing their work. The physicist and the philosopher would otherwise perhaps only meet socially at the gym or the faculty club. The library continues to cut across disciplinary boundaries. At UCSB we assist faculty who are grappling with emerging mandates to preserve their research data, deposit their publications in open-access repositories, and digitize course materials otherwise only available in print. We also cut across the boundaries between faculty, students, and the community by presenting general interest lectures, workshops, and providing free access to scholarly resources not otherwise available to the public.

Spatial processes are built into many ordinary library business practices. While we promise to borrow books regardless of their location via inter-library loan, space is actually an important part of the process. Distance is a primary factor in choosing which library to request a book from. However, the system we use also balances workloads and lend-to-borrow ratios. If UCSB is borrowing too many books from Stanford and Stanford is experiencing high demand from other libraries, the system we use will automatically re-route requests to more distant libraries. Even the way books are arranged on the shelf is spatial. Because we use subject-based classification schemes, the stacks are a manifestation of Tobler's Law: books on similar topics are shelved near each other.

Some libraries are now implementing systems that guide users from a record in the catalog to the correct row of shelves in the stacks--essentially marrying the library catalog with a building navigation system. Here at UCSB, we recently disabled a similar home-grown system that we determined was too expensive to continue to maintain. However, our building is complicated to navigate and we are currently moving massive amounts of materials in and out of the building as well as changing the floor plan. We know our users need help getting to the remaining print materials, so we are evaluating both FOSS and commercial products that will not only be more easy to update, but will also get users closer to their target than the previous system.

Another building navigation system under consideration will guide users towards available computer workstations. Even with ubiquitous laptops, there continues to be high demand for desktop computers in the library. Commercial systems have sprung up that show which computers are currently available. In the future, we anticipate showing which areas of the library have available chairs and tables. It is not a stretch of the imagination to suggest deploying sensors that would measure ambient noise levels, offering users a choice between quiet, contemplative spaces and active rooms filled with conversation.

At UCSB there is also a certain level of excitement in the library. We have an all-new management team that is attempting to revive long-dormant collaborations with partners across campus. The Alexandria Digital Library was designed and implemented by computer scientists, geographers, and librarians working together, but the project has been left practically untouched for the past eight years. Recently we have begun to identify pieces of this effort that can be revived using current technologies. The first of these is the ADL Gazetteer, a place-name dictionary that is combined with a feature-type vocabulary (are you looking for the state of Mississippi or the Mississippi River?), spatial hierarchy (the city of Santa Barbara is within the county of Santa Barbara), and temporal change (East Germany was only a place between the years of 1949 and 1990). The gazetteer will be used as the spatial facet in a new, overarching digital library system built on open source software.

We also have a major construction project underway, and are actively seeking input from our user community on how the future library will operate. Will we continue to offer general desktop computers, or do we need to focus on fewer but more specialized workstations? In an era where many (if not most) library materials are available online, what is the best way to provide face-to-face services to people in their departments or their dormitories? If neither the physicist nor the philosopher need to come to the library to access their journals, what services can we offer to continue the tradition of a trans-disciplinary venue?

Today, opportunities for library to contribute to enabling smart campuses are limited only by time and money. Ever conscious of scarce resources, we continuously look for cost-effective technologies that we can implement affordably. At the same time, we realize that it is vital for us to contribute our expertise in information architecture and information seeking behavior to campus-wide efforts. My participation in *Advancing the Spatially Enabled Smart Campus* will provide an opportunity to discuss these issues with a wide variety of potential partners.

Questions for the Spatially Enabled Smart Person on a Smart Campus

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For much of my professional career, I have promoted the importance of documenting and understanding the diurnal space-time patterns of human movements and activities in cities (e.g., see Janelle, Goodchild, and Klinkenberg 1998; Janelle 2012). The recent research focus on smart cities has demonstrated the theoretical insights and practical benefits that can be derived from such documentation (e.g., Harrison, *et al.*, 2010; Batty, *et al.*, 2012). Clearly, the integration of information and communications technologies (ICT) with geographically embedded and mobile sensors has enabled flexible temporal and geographical referencing of data to display information of all kinds—opening a plethora of research and problem-solving capabilities not thought possible as few as ten years ago, much less four decades ago when I initiated research on the space-time geographies of cities. But, now, I wonder—Where is this technology taking us? Are there downsides? What are we giving up? What are the risks? In addressing these questions, it is ironic that my responses are in the form of more questions. In large part, these concerns derive from humanistic fears of change and from threats to the values embedded in existing socio-economic structures and in traditional problem-solving practices. The questions listed below are exemplary rather than exhaustive; I hope to add to this collection of queries over the course of the specialist meeting.

What should we guard against?

- How can we make use of automated handheld, wearable, and vehicle navigation/information tools without losing our innate human capabilities to think spatially?
- How can the individual exercise control over information access without being overwhelmed by targeted automated information services?
- Do we seek ICT-tethered dependence in structuring and carrying out our daily routines and lifetime trajectories or can these technologies be designed to enhance our individual autonomy over space and time?

Of course, the smart (cities/campuses/buildings/etc.) movement has emerged with a primary focus to enable opportunities to bring our lives in better alignment with environmental and social constraints. Indeed, there are enormous opportunities, some already underway, and others not yet on the drawing boards. As educators, we need to be conversant in how these technologies intersect with intellectual perspectives and to nurture those that promote

opportunities to engage students productively and creatively. There are significant opportunities to use local campus environments as platforms for students to learn problem solving, research approaches, and collaborative skills from a broad range of disciplinary perspectives that will equip them for a lifetime of innovative and thoughtful engagement.

What opportunities should we nurture?

- Seeing time as a critical non-renewable resource in the context of the human life span, how can the smart campus be an incubator where ICT design and deployment enhances general human efficiency and effectiveness?
- How do we move beyond our home-based smart campus to the global integration of smart campuses?
- In what ways can we contextualize the campus environment to address broader regional, national, and global issues (including environmental sustainability, cognitive clarity, and social cohesion)?
- How can we create and demonstrate in the campus setting collaborative systems of knowledge integration for framing and solving problems?
- Can the campus position itself as an incubator for innovation through smart technologies, especially by engaging students in conception, design, implementation, and evaluation?

I trust that this specialist meeting will address such questions and draw attention to the need for integrating smart people in smart ways with smart infrastructures for smart outcomes.

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Advancing the Spatially Enabled Smart Campus

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The term “Smart Campus” is a very broad term that can be applied to campuses of varying complexity. My belief is that a campus requires a greater level of complexity than a single building or space. That is not to say that a single building or space wouldn’t benefit from some of the strategies and methods used by a traditional Smart Campus. In general a campus today would have buildings with various types of space assets, multiple infrastructures including but not limited to transportation, utilities, and communications. I do not believe the term “Smart Campus” should be based on the technological complexity of the infrastructure but rather the campuses development plan. A campus that has just begun to implement some of the necessary sensors and networks of a traditional Smart Campus, they can still see immediate benefits and return on investment.

I am not informed to the entire Smart Campus infrastructure UCSB has developed to date and whether or not UCSB is considered a “Smart Campus” or not. We have done work with Physical Facilities who been implementing a system that logs and can help analyze the energy usage data for the buildings on campus. This single component, which is included as a part of most of the smart campus solutions that are available today, has given Physical Facilities an incredible resource for analysis and determining usage patterns for the campus. By logging the data to a relational database system with space and time functionality they are able to run complex analytics on the datasets that weren’t possible with analog data. They have also been working to replacing the existing electric meters which require manual monthly readings with automated 15minute interval sensors. The new meters have greatly improved the data quality and resolution. Lastly, since it is in a relational database system which is interoperable with many programming languages, I have been able to leverage the dataset to bring transparency to the campus and raise awareness regarding energy usage on campus via the UCSB Interactive Campus Map.

There are many different solutions available for a campus that wants to become a Smart Campus. Esri and IBM both make popular solutions and offer services to help implement these solutions. For now, I don’t believe there is one solution that is better than the other. Campus around the world can vary in size, resources, and requirements. It would be very hard, as an engineer to produce a solution that fits every campus.

If I had to choose one for my own campus, I would most likely use the one that best suites our needs, is widely adopted already, or has a high level of interoperability with other solutions. A completely unique/proprietary Smart Campus solution wouldn’t allow for collaboration

between other campuses nor utilize any tools that get developed by other campuses and organizations.

There are some components which are included in all available Smart Campus solutions available today. A database system with space and time functionality is almost always a critical part of the Smart Campus infrastructure. The database system is an efficient way to store the datasets and perform spatial and time-aware functions to the data. There are many different solutions available to fill this requirement including but not limited to PostgreSQL, MongoDB, Solr (powered by Lucene), MariaDB/MySQL. A communication infrastructure would be required for the sensors and networks to interact. Currently TCP/IP over physical communications lines is the most widely used and provides immensely levels of interoperability with connectivity to the World Wide Web. Special considerations may need to be used and ultimately it would depend on the sensor and implementation used.

Volunteered Geographic Information (VGI) has the potential to play a critical role in gathering information, quality assurance, and decreasing the response time for data acquisition. Smart phones and mobile devices are becoming ubiquitous among the general population. *"Citizens as sensors: the world of volunteered geography"* by Mike Goodchild covers the idea of using people's mobile devices and VGI to build datasets. One idea I've had while working on the UCSB Interactive Campus Map was to create a VGI module for the UCSB Interactive Campus Map Phone App. The user would be able to opt-in (or not) and the module would collect GPS+WiFi signal strength readings for the UCSB WiFi Network when they used the app. The data would be automatically contributed to the UCSB ICM team which could produce a continuously up to date wireless signal strength map. Smart phones could also be used to contribute information during emergency situations as well. An "emergency" module could be developed that interfaces with UCSB Emergency Management and/or the UCSB Police. The specifications of the module would depend on their available resources and requirements.

UCSB already has infrastructure in place that can help them understand diurnal and seasonal demographics of campus buildings and spaces. The energy usage data Physical Facilities is collecting could be analyzed and used to predict periods of above/below average usage and react accordingly. If they were able to log the energy usage per room instead of per building (improve granularity of data), even more complex diurnal and seasonal patterns could be discovered.

The UCSB Interactive Campus Map project has been another very successful project that has brought students into the technical aspect of implementing these smart campus solutions. A majority of the datasets the Interactive Campus Map references have been created by undergraduate and graduate student volunteers. Some datasets were at the request of Facilities Management, other were suggested and created from scratch by the students themselves. This collaboration between the students and Facilities management has been beneficial for both sides. It wasn't until recently that we were able to collaborate due to quality assurance and technical hurdles. The workspace the volunteers work in is versioned and isolated from the authoritative datasets. Edits are required to go through a quality assurance and quality control

process and can be imported into the authoritative datasets at their discretion. The students are able to experience the unique challenges that come with working with real-world datasets (which are usually imperfect) and Facilities Management can benefit from the volunteered work and improved datasets.

The possibilities for what a Smart Campus can do or be are evolving as we learn more every day. I feel that UCSB is beginning to take steps towards becoming a Smart Campus but there is lots more that can be done. I am looking forward to the opportunity to learning more and contributing what I have learned and experienced over the past year while working on the UCSB Interactive Campus Map.

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Advancing the Smart Campus with Open Data

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The Open Data University

Over the past years, several universities around the world have joined the open data movement. The first initiative of this kind in Germany was started in Münster, with the Linked Open Data University of Münster (LODUM) project.¹ The goal of LODUM is to open up and connect the rich data sources maintained by the university, both concerning administrative and research data. Spatial aspects play an important role in many scientific resources, ranging from obvious examples such as historic map collections to less obvious ones such as spatial analyses of active pharmaceutical ingredients. On the administrative side, geographic information is required for many planning aspects, from facility management to course scheduling down to the individual student planning her classes (which is especially challenging at a non-campus school like Münster, which has its buildings scattered across town).

The use of the Linked Data approach [3] provides a set of standards for semantic annotation and integration. Following these principles, a number of datasets have been released and enabled applications to evaluate scholarly activity [1] and for indoor navigation on campus [2], among others. Moreover, the data published in LODUM drive the campus app,² which supports students in many of their day-to-day tasks. Since the beginning of 2013, the Linked Data for eScience Services³ project explores the potential of this approach for applications in the library context.

Lessons learned

LODUM is just one example of such an open data initiative. A growing number of universities have joined this movement, and platforms such as Linked Universities⁴ have been established for exchange and communication between them. We anticipate that a data platform will become as common as a website in the foreseeable future (both for universities and other public institutions). However, currently, such initiatives still strongly depend on individual efforts, and applications that put the published datasets to use are required to demonstrate the utility to a broader public. Convincing administrators to give away data they often see as *theirs* can be hard, despite the promise of improved data quality through transparency. Flagship applications such

¹ <http://lodum.de>

² <http://app.uni-muenster.de>

³ <http://lodum.de/life>

⁴ <http://linkeduniversities.org>

as apps for students or campus energy management⁵ are key to increase the willingness of the campus “inhabitants” to contribute the data that enable a smart campus in the first place. Moreover, they show administrators what can be done with open data once the rather abstract data cleaning and integration process is complete. Such flagship services hence also help to secure long-term funding. At the same time, coordination across different universities, especially in terms of shared vocabularies used for data publication, ensures interoperability and makes it easier to develop applications once, and then reuse them at other schools.

Advancing the smart campus

While some promising first steps towards the smart campus enabled by open data have been made, we only start to understand the fundamental changes this implies to scientific data management and evaluation, as well as campus management and student services. Spatial data is a key enabler for integration in this setting, allowing the scientist to join previously disconnected datasets through their spatio-temporal references and retrieve relevant data based on spatio-temporal scope. This bears a great potential for libraries, which are in the process of redefining their role from literature management institutions towards data curation and e-science service centers. The corresponding transformation process still leaves a number of open research questions, especially concerning accessibility and modeling of spatio-temporal data [4]. The experts to solve these problems, however, can actually be educated in the realm of such a smart campus initiative. Project classes can get involved in developing prototypes for required solutions, and graduate students can work on the theory involving topics such as modeling, transparency, privacy, and usability—of published datasets, applications, and even the campus itself. In the long run, a smart campus based on open data can become an ecosystem that spans research, teaching, evaluation, startups, student services and administration.

In order to reach this goal, a clear open data agenda is required for each campus, similar to the one just released for New York City.⁶ This requires substantial change in many institutional workflows and responsibilities concerning quality control and publication rights. Concerning spatial data, more research is required to identify all datasets with direct and indirect spatial references. The potential of these datasets for integration with other datasets needs to be explored, especially concerning the development of new scientific and administrative services. In order to reduce the efforts for these undertakings at each individual university and to jointly develop standards for data annotation and publication, exchange and interaction between the participating universities is vital.

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⁵ <http://losangeles.usc.edu>

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What Makes us Smarter on a Campus?

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On campuses, we tend to think of ourselves as being among the smartest people. Yet, some of the ways in which we handle resources and opportunities are stuck in academic Stone Age and could use some retooling. Surprisingly, our core business of research and teaching suffers most from arcane resource and information management, characterized by proprietary and largely inaccessible silos of research data and education materials. But universities also offer fantastic interdisciplinary settings for efforts to improve this situation.

The notion of a smart campus, with its roots in smart cities, has been used for a broad range of ideas around the use of technologies in support of campus life and management, often focused on building infrastructure. This specialist meeting takes stock of these ideas and enlarges the spectrum further, by including knowledge infrastructures for research and teaching. One can easily argue that an optimized management of campus resources and support for campus “users” should include research and teaching resources and their use by scientists, students, and administrators. The role of spatial enablement is, it turns out, equally or even more beneficial in these tasks—and has hardly been tapped into so far.

My position at the meeting will be that, since it is tools that make us smart, we need to design and evaluate *tools for spatially and semantically enabled exposure and access to scientific contents*. Based on an ongoing project at the University of Münster (<http://lodum.de>) and a new initiative at UCSB’s Center for Spatial Studies (<http://spatial.ucsb.edu>), I argue that such efforts are best planned and carried out in cooperation with campus libraries. The second main allies are champions from disciplines that understand and promote the benefits of sharing scientific data and linking them spatially and semantically.

In particular, my experience in these two efforts so far suggests thinking about best practices along the following lines:

1. *engage librarians* and library technologists in discussions on how to spatio---temporally and semantically enable access to library contents;
2. *approach campus leadership*, jointly with the library, and argue for coordinated efforts in the context of mandates for open access, inter- and transdisciplinary research, cluster funding, scientometrics, e-learning, digitizing resources, improved and novel library services, etc.;
3. *build experimental tools* and platforms, in cooperation with champion users on campus (consider: genomics, brain research, digital humanities, economics . . .), to demonstrate the potential of opening up research data and making them spatio-temporally searchable and analyzable.

It helps to set tangible and measurable goals for such efforts and discuss them with users and stakeholders. What benefits should researchers, educators, students, and administrators obtain from them?

As a start, I suggest it should be easy for researchers to:

- publish data and associated analyses, papers, presentations etc.
- find and access data based on place, period, and properties
- analyze the spatial and temporal variation of studied phenomena
- combine data from multiple sources, spatio-temporally and semantically
- analyze distributed data rather than download data for analysis.

Similar lists can easily be drawn up listing benefits for students (think of problem-driven learning), administrators (consider evaluations) and any other actors on campus.

The bottom line argument for such efforts is that campuses, just like cities, compete for residents. Researchers (like myself) tend to choose campuses offering the best environments for a smart use of resources. As experts in spatial thinking and computing, we can propose a range of unique selling points to campus administrators, based on the integrative roles played by space and time.

Keys to Developing a Smart Campus: Communication and Collaboration

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When I started working at UMass in Facilities and Campus Planning six years ago, GIS was a tool for making paper maps that hung on office walls. Now, UMass Amherst has recently formed a GIS Steering Committee with high level membership that includes the CIO, Vice Chancellor of Facilities and Campus Services, the Directors of Campus Planning, Design and Construction Management, Physical Plant, the Vice Provost and Deans from several of the colleges on campus. This marks the moment that the idea of an Enterprise GIS has become institutionalized and will have the heft of the campus leadership behind its implementation. It is now understood that GIS is more than paper maps. It is an information system with the architecture and scalability to provide the framework for tying most of the other data and information systems on campus together to create the basis of a Smart Campus. A key aspect of this technology that makes it so valuable is the ability to share information and visualize it a manner that fosters better communication and collaboration.

Like most college and university facilities divisions, ours was primarily a CAD-oriented operation with GIS used to print out the Campus Map. I was hired as a Planner, but mostly for my GIS skills. A week before I started, my boss left and since my predecessor had been gone for almost six months, most of the responsibilities had been reassigned. Since nobody really knew what I did, except make maps, I had a lot of time to look around and reflect on how my new environment worked, how it used technology, and what I could do to help. Seeing CAD all around, I tried to take off my GIS evangelist hat and really think about the appropriate technologies for this environment. I was fortunate to get involved in several new technology initiatives which included the research and selection of a Computer Aided Facilities Management (CAFM) system. In the end, I came to the conclusion that GIS is really the technology that can tie all of the other data systems together and has the analytical and visualization tools to be a truly enterprise decision support tool for all levels of decision makers. The evolution of the technology to not only provide the scalability to allow the harnessing of data within the buildings, not just the outside environment, plus making that data available in easy to use online applications, just reinforces that conclusion.

Not only does GIS create a better environment for communication and collaboration, elements essential for a Smart Campus, I would argue that it takes communication and collaboration to implement the technology successfully. At UMass we have been fortunate that collaboration was what got GIS started at the university through a joint project with the Town of Amherst and Amherst College to do the initial flyover and basemapping project in 1999. By partnering and combining funding, the initial project budget had well over half a million dollars and we were able to do 1" = 40' scale mapping with 2' contours, surveyed all utility points and had 0.25" resolution digital orthophotography for a very complete and accurate starting point. Since then, the entities have collaborated to collect orthophotography again in 2004, a whole new flyover and base mapping project that also included LiDAR to provide 1' contours in 2009, and are joining a regional collaborative effort to collect new orthophotography and LiDAR in spring 2014. The University and the Town of Amherst were also collaborators and early participants in ESRI's community base mapping program and were featured early as an example because of the richness of our data. The two entities were also the first to be recognized in a press release when Google Earth launched its Cities in 3D program in 2008.

UMass benefitted again from collaboration when Campus Planning brought on board Alexander Stepanov, then a Ph.D. student in Operations Research who had finished his M.A. in Regional Planning at UMass, to assist me in the development of our GIS capabilities. With Stepanov's unique combination of insight into operations research, and ability to both see the big picture and understand why the tools are needed, and also be able to do the hard core programming, we began developing many ideas and prototypes for how to incorporate GIS into the operations at the University. We started by using Applied Geographics General Purpose Viewer (GPV), a stored procedures based application that uses ArcGIS to create an easy to use interface for staff. These tools included the ability to view floor plans within building footprints, utilities (linked with photos and record plans), public art on campus (with photos and info about the artists), tree inventory and our historic building inventory and report. We also began collaborating with a developer in Administration and Finance Systems (IT for operations) to develop a prototype Project Information Management System (PIMS) that incorporated GIS web parts into Sharepoint to provide access to all of the project management data through a map. All of these prototypes were beginning to educate people that GIS was more than a paper map and developed interest in using the technology for operations.

I believe that the big break for GIS at UMass came with the success of the Campus Master Planning process. Campus Planning was charged with creating the first comprehensive master plan for the campus in more than 40 years. We firmly believed that the process must be open, transparent and include as much community participation as possible. We immediately began thinking about how GIS could enhance the project more than just providing the traditional mapping and analysis role, but as a tool to engage students, a traditionally hard to reach population. Unfortunately we did not have the type of server environment to support heavy duty use by a lot of people. That is where ESRI's new Community Basemapping and online GIS technology provided the answer. First we created the "Likes and Dislikes" app

(<http://www.umass.edu/cp/maps.htm>) that allowed the campus community to tell us what they thought of the campus and once students saw the application at an event in the campus center, news of it spread and so did the participation. Then we created the “Master Plan Explorer” which allowed us to present the draft Master Plan and allow people to learn about it through clicking on areas or new buildings and getting more information about it and tell us what they thought. Now we are creating the “Campus Master Plan Story Map” to keep the plan alive and accessible to people. The best moment was when the Chancellor endorsed the Master Plan and said the thing that impressed him most was that it was supported by so many different quarters of the campus community. The innovative use of GIS as a communication and collaborative tool was a huge part of engaging the community, documenting their input and allowing them to see it, and ultimately getting widespread knowledge and acceptance of the planning process, or what we like to call “creating a culture of planning.”

UMass is now well on its way to creating a Smart Campus by developing the infrastructure to bring information together and make it easily accessible to all decision makers in the many ways they need it to visualize and understand it. We have hired Stepanov to a full-time GIS Architect position that I fought hard to put under the IT infrastructure even though he still has an office in Campus Planning, another example of collaboration. We now have great data, a powerful hardware architecture, incredible software tools to support a Smart Campus. However, I would argue that the work flows and procedures that we are developing, along with the cooperation among the many people involved, are the real keys to the success of our endeavor. The configuration of our GIS Steering Committee is reflective of the understanding that communication and collaboration are keys to a Smart Campus.

Influencing Behavioral Change through GIS/Smart Campus Initiatives

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How can we use GIS and the Smart Campus Initiatives to help us improve sustainability efforts? Are there any best practices to help us garner high levels of participation? How do we take advantage of campus data sets to display information? How do we spatially display this data to so it makes sense to end users and helps influence and incentivize positive behavioral change? These are just a few of the questions we are looking at from the sustainability perspective.

Let's explore just one area, energy conservation, through behavioral change to look at this issue. Energy conservation is an important component in any plan to reduce Greenhouse Gas (GHG) emissions from building energy use. Our new President, Janet Napolitano, has set a target of climate neutrality by 2025. In order to achieve this level of energy conservation it is essential that a program inform energy consumers of their present and historical energy use, provide them with examples of energy-saving measures and activities, and give frequent, even real-time, feedback on how their energy use compares to "social norms." In addition, a successful program builds on making users "energy aware" by motivating individuals to get involved, identifying and supporting committed individuals, and rewarding users for reducing energy waste. A number of programs on campus induce behavioral change and reduce energy waste, such as PowerSave Campus, LabRATS, and The Green Initiative Fund. However, more robust efforts, like the Smart Campus Initiatives, need to be taken in order to meet the aggressive emissions reduction goals our campus has set. UC Berkeley estimates that they will see a persistent electricity consumption reduction of 3-5% through their behavioral change/energy incentive program,¹ and evidence from campus residence halls indicates that even higher reductions are potentially achievable. UCSB forecasts a 5% reduction in total electricity use through the Energy Incentive Program (EIP), which would reduce CO₂(e) emissions by 3,149 MT CO₂ E annually.

% Reduction	Energy savings (kWh/Year)	Electricity cost savings (\$/year)	GHG Savings (MT CO ₂ E/yr)	Program costs	Payback Period
3% Reduction	6,390,595	\$671,012.42	1,916	\$558,750	8.3 months
5% Reduction	10,651,001	\$1,118,355.07	3,194	\$558,750	4.9 months
10% Reduction	21,302,001	\$2,236,710.13	6,388	\$558,750	2.5 months

As part of the University of Cambridge's Energy and Carbon Reduction Project, a laboratory pilot program (that did not take advantage of GIS tools or spatial displays) at the university's

Gurdon Institute utilized behavioral change towards energy use to successfully garner energy reductions throughout a department.ⁱⁱ The pilot program achieved a 76% participation rate across the department and achieved an overall reduction of 19% in energy usage over a 5-month period.ⁱⁱⁱ

Looking at behavioral changes as a portion of the mechanism to help fund programs is a strategic way to move initiatives forward in the current financial climate at public universities. If we can successfully develop visual imagery via GIS/Smart Campus initiatives to spatially display information that could influence users, this same strategy could apply to the areas of waste, water, procurement, food, the built environment, transportation, the landscape/biotic environment, etc.

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Campuses Need to be Fully Spatially Enabled

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Colleges and Universities strive “to create knowledge, to open the minds of students to that knowledge, and to enable students to take best advantage of their educational opportunities.”¹ A spatially enabled campus is better suited to the creation and dissemination of knowledge and what is currently lacking to achieve a fully spatially enabled campus are methods of accurately determining individual location and presence.

What needs to be in place for a spatially enabled campus?

Many campuses have a geographic information system, space system, and facility and asset management system(s). Spatial enablement starts with having these systems in place and having them integrated by sharing common spatial nomenclature so data can be matched spatially. For example, floor plans georeferenced so that they are placed in the campus context and assets that are located by room identification and/or coordinates. This integration can be expanded to include human resources, financial, transportation, security and other systems. Not until a core of integrated spatially aware systems is in place can the full potential of an enabled campus be realized – a campus where individuals can take full advantage of the campus context and a campus that can use the presence of individuals to support planning and operations. Until the location of the individual is accurately known there is no way to answer these questions: “how close is?”, “how to get there?”, “what is going on nearby?”, “what information should be conveyed to this person because they are here?”, “where is this person?” and “Is there anybody present?”.

Thinking big requires a campus that is spatially aware of the individual and critical assets in its entirety across its facilities both within and outside of buildings with a level of accuracy that is not achievable using current GPS and Wi-Fi methods. There must be locational infrastructure on which the campus population and visitors can rely. To achieve this end requires development of location technology and devices that are as ubiquitous as data jacks, life safety systems, and lighting fixtures. The technology is available now and all that is needed is the demand to create the financial incentive for development. Two methods of location are needed. The first is enablement of the individual through a smart device to accurately determine their location inside and outside of buildings and the second is the ability of campus systems to identify locations where individuals are present independent of the presence of a smart device. Privacy must be protected so sharing of location and individual identity should be left to the individual and presence detection needs to be anonymous.

One possibility for the individual to identify their location could be the development of a uniquely identifiable transmitter that incorporates ultrasound and radio waves (like blue tooth) that emits simultaneous sound and radio signals to enable smart devices to determine their precise location based on a dataset of transmitter locations, distance based on lag between

radio and sound wave, and triangulation of multiple sources. The ability to detect the presence of individuals in a location could be provided by sensors that detect motion and relay presence via wifi or other network system to a central system and database. This method of presence detection will provide better information for building usage, systems and emergency response than requiring the presence of a smart device (which can be present without a person or an individual may not have one).

The transmitters and sensors could be embedded in life safety or lighting systems equipment like exit signs, emergency lighting, or light switches. This would be similar to current implementation of motion detectors in the light switches. This way the devices can easily be incorporated into new construction and campus furniture and they can be easily retrofitted into existing facilities. They would need to be inexpensive, have low power requirements and remain functional in the event of a power outage. The technology, methodology, and algorithms should be unencumbered by licensing and patents to minimize costs. With the advent of building information modeling for new construction and renovations there is the capability to incorporate the devices into geo-referenced three dimensional models and extracting the transmitter and sensor locations.

What opportunities does spatially enabling a campus create?

A spatially enabled campus that enables individuals to be spatially aware of the campus context and that enables the campus to be aware of presence can be leveraged to support creation and dissemination of knowledge, to enable students to take greater advantage of the educational experience, and to allocated resources appropriately.

- (1) **Information collection** that supports campus planning and operations so that facility systems, services and energy savings maximize resources for pedagogical priorities. This spatially aware information supports efficient use of space and energy, a safe campus environment and provides core information needed to support programming and physical planning. Information collection methods include user generated geographic information, crowd sourcing, presence information collection through sensors. Examples of applications include crowd sourcing facility condition issues, synthesis and analysis across time with spatially integrated systems and datasets to develop holistic campus models for usage of facilities over time to determine operational efficiencies, the ability to implement hoteling to reduce office space requirements, and development of dashboards that support operational activities in real time. Why clean a room that no one has been in since the last time it was vacuumed?
- (2) **Creation and dissemination of knowledge** by reducing barriers to collaboration. Examples include ease of locating collaborators, arranging meeting locations, changes to teaching methodology whereby faculty hold office hours where the students are located by broadcasting availability and location.
- (3) **Geo-centric Information sharing** by broadcasting information to individuals within a geographic area or posting information to a geographic location for public or group use. Examples include broadcasting educational, amenity related and emergency announcements to individuals within a portion of the campus.

(4) Campus Amenity that is used for social interaction.

Examples include peer to peer “this is where I am (or we are) now.”

How can the case be made to spatially enable a campus?

The case for a fully spatially enabled campus needs to be made with university administrators. Having industry examples that illustrate the usefulness of a spatially enabled campus will assist in this process. These examples should be focused on innovations in education, planning and/or operations that have led directly to improvements and/or savings. The examples need to be showcased in appropriate journals (not an ESRI publication) and should not focus on the spatially enabled campus but on the innovation itself. For example (hypothetically) an article in the *Chronicle of Higher Education* detailing a program by which faculty have dramatically increased their face time with students by moving office hours out of their offices into dynamic learning spaces (which by the way was made possible by a spatially enabled campus). For these examples and for full implementations, measurement should be in place to determine usefulness and return on investment. Usefulness might be measured by determining whether the spatial infrastructure is being used regularly and has been incorporated into systems and decision making. The ROI will need to be determined by demonstrating improvement in services, energy savings, and more efficient space use resulting in reduced space needs. We will likely find that over time the spatially enabled campus will be the expectation and not the exception.

¹Harvard College Mission Statement

Sustainability and Smart Campuses

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I. The Smart Campus

The implementation of sustainability in university settings is driven not only by the urgent need to stop the depletion of the Earth and contribute to healthier communities, but also to deal with limited operating budgets. The concept of sustainability was widely welcomed after the private sector recognized economic gain derived from the implementation of sustainable practices. The complexity and size of campuses offer opportunities to improve operations and increase the efficiency of human and financial capital.

Smart campuses should operate with fewer resources and promote socially responsible practices. Additionally, smart campuses should integrate cutting-edge technology not only to operate campus components, but also to provide the most efficient and intelligent systems to support research and teaching endeavors.

Some aspects to be considered to operate smart campuses are:

- Efficient use of spaces and assets (i.e. online learning, e-surplus database management)
- Energy saving and efficiency (i.e. adequate indoor temperature, light auto-shutdown, student schedule coupled with minimum transportation needs, electric car charging stations)
- Re-use of resources -less for more (i.e. water bottle refill stations, bike sharing and carpooling)
- Indigenous materials, native landscaping and composting, recycled water and efficient irrigation practices
- Promoting new inventions and technology for green practices
- Upgrading obsolete buildings, infrastructure, vehicles and machinery
- Establishing intelligent systems to promote conducive learning environment (i.e. teaching technology, air quality, human interaction with nature)
- Promoting among faculty members the implementation of new creative teaching methods to effectively engage the digital-native generations

II. Leveraging on crowdsourcing and geospatial technologies

The internet had increased exponentially the speed in which communication travels from citizen to citizen and from communities to communities. Lessons learned and best practices from peer institutions are shared rapidly through institutional channels as well as informal means of communication such as social media. Sharing data of and within campuses is essential to understand the way the components operate and interrelate; a master interactive map – with a data mining mechanism- should be in place in any given smart campus. Proposing changes and taking action in a timely manner, based on real-time data-driven analyses, may result in a more efficient operation.

Smart campuses should leverage on volunteered geographic information (VGI) and geo-enabled web services to increase community capacity building. The mission of the Office of Sustainability at Texas A&M University is to educate the community about the importance of sustainability and promote sustainable practices. I recently facilitated the collaboration between the Office of Sustainability, the Map & GIS Library and the GeoInnovation Service Center. The 3-unit group is planning a massive crowdsourcing data collection event, [Crowdsourcing for Aggieland Sustainability](#), to help identifying and interactively map all sustainable items across campus, geotag any issues to be resolved or malfunctioning of campus features, and propose wish-list items at specific locations. The outcome of this VGI event will help the Office of Sustainability to review pressing reported issues, innovative proposed ideas, and also obtain an inventory of sustainable initiatives present at Texas A&M. An existing green fund may allow solving reported issues and implementing wishes proposed by the campus “citizens.” We plan to rely on geospatial technology to display real-time data, allowing the “crowd” to collaboratively and interactively collect the data while a needed interactive map will be generated to integrate the sustainable components of our campus. Likewise, other initiatives using smart devices can be launched to promote green practices. For instance, campus users could rely on phone apps to measure individual gas savings by measuring walking, biking or carpooling, apps to calculate the shortest route, apps to show water or energy refill stations, etc. Currently, transportation services operate GPS-enabled mass transit units, allowing riders to track buses location from their smart devices. Additional efforts may be proposed and implemented to increase efficient and intelligent systems at our fingertips.

III. Smart Campuses Fueling Intellectual Development

Often times we learn about workshops and research groups studying water management on campus, green roofs opportunities, energy-efficient building design, and other initiatives. Interdisciplinary studies and research are promoted across campus to challenge students to learn real cases and find real solutions.

The objective to generate a smart campus with sustainable grounds may fuel many opportunities to innovative design, technology development and patents, critical thinking and problem solving. The availability of databases and real issues to be solved can serve as a learning lab for students, giving as a result an immersive educational experience. Programs of community outreach can be promoted among different disciplines, allowing students to apply successful concepts already tested within the campus settings. Funding to promote green and collaborative initiatives can be offered to researchers and faculty members who lead research and teaching endeavors. Texas A&M University has about 900 student-run organizations, each organization could be required to launch at least one sustainable initiative. Teaching initiatives should be modeled towards a smart campus and with the overall goal to fuel discovery and enhance the learning experience of every undergraduate and graduate student.

Smart campuses can be promoted not only through a top-down approach with university officers and administrators making decisions, but also as a grass-root movement with everyone committed to generate and analyze accurate, real-time, relevant data.

Advancing the Spatially Enabled Smart Campus

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The advent of high-resolution LiDAR (Light Detection And Ranging) data over the last decade has created unique opportunities for integrating 3-dimensional structural representation of urban and natural landscapes with traditional geospatial technologies. Spatial maps and services are no longer restricted to portraying 2-D and 2.5-D layers of real world objects – holistic structural representation of surfaces and objects with high spatial resolution is now feasible. We contend that any modern “spatially enabled smart campus” should make use of 3-D data when appropriate. A 3-dimensional representation of buildings, trees, and other campus features not only enhances spatial navigation (e.g. real-world walk-throughs), but also provides valuable urban land-use metrics that can be used to improve campus sustainability and planning (e.g., calculating carbon footprint, solar insolation modeling, capturing changing ecosystems, flood modeling, etc). Repeat observations of the campus allow for the creation of 4-D datasets, with the added temporal component documenting historic snapshots, campus growth, and rates of change.

Aerial lidar provides sub-meter resolution data over large spatial extents (e.g., whole cities/states), while terrestrial lidar provides cm-level resolution of smaller scenes (typically < 1 km, but can be larger depending on time and effort). Burgeoning, inexpensive, “portable” lidar devices (e.g. Kinect sensor) provide possibilities of real-time use by the general, non-technical population and can extend VGI (volunteered geographic information) to include 3-dimensional data. The 3-D data can then be visually represented in a number of ways: laser point returns (“point cloud”), constructed real-color surfaces (e.g. triangulated surface meshes of Triangulated Irregular Networks, or TINs), as well as traditional high-resolution raster/vector products. The data can be observed as a simulated 3-D experience through stereoscopic and anaglyphic methods, or interactively projected on two-dimensional planes through 3-D computer graphics rendering technologies (e.g. Google Earth and WebGL). The rise of modern GPU (Graphics Processing Unit) accelerated web browsers over the last 1-2 years on desktop computers, tablets, and mobile devices allows for 3-D data to be easily visualized and manipulated. Such technological advances are “closing the gap” between expensive, technical lidar devices/software and the common user – the commonplace “map” is quickly becoming a digital, interactive, multi-layered, search-enhanced 3-D simulation/augmentation of the real world.

Adding a detailed 3-dimensional component to campus features has a number of immediate benefits. Building areas and volumes can be accurately represented, providing a clear picture of campus resource use. Accurate 3-D modeling of annual solar insolation distribution can be used

to distinguish shaded and sun-lit areas; this can be essential information for land-use planning (placement of benches, trees, lawns, ecosystem services) and lowering the campus carbon footprint (e.g. optimal placement of building windows for maximum natural light). Micro-topography representations of the ground surface can be used for flooding and natural hazard assessment (e.g. tsunamis). Such 3-D information can be regularly acquired (e.g. on an annual basis) to provide historical records of campus growth and change. The launch of interactive “timelapse” capabilities in geospatial services (made famous in Google Earth) has shown the possibilities and importance of capturing the rapid changes in our environment. While some temporal 3-D data is already available to campus planners, in general such datasets have not been easily provided to the general campus community. The use of WebGL-enabled browser mapping engines can help put detailed 3-D/4-D data into the hands of ordinary users.

We have made extensive use of aerial, terrestrial, and portable lidar data around the Santa Barbara area (Figures 1-3 provide our examples of typical lidar-acquired scenes). We make some of these datasets available to explore in Google Earth (see links below). In addition to data acquisition, we have created a number of lidar processing software pipelines, including: lidar point cloud feature detection, surface construction, visualization, and web mapping representation. We believe our data, tools, and methods can be combined with existing campus mapping efforts to provide a more comprehensive 3-dimensional picture of the campus and its resource use. Such innovation will not only be useful for creating a “21st century campus experience,” but can also be extended to apply to any modern urban community.

Sample Google Earth Lidar products:

http://www.geog.ucsb.edu/~bodo/KML/SedgwickReserve_25cmDEM.kmz

http://www.geog.ucsb.edu/~bodo/KML/SantaCruzIsland_PozoCatchment_20cmDEM.kmz

http://www.geog.ucsb.edu/~bodo/KML/ParmaPark_25cmDEM.kmz

Figure 1. *An aerial lidar scene of the UCSB campus from 2005. The 3-D point cloud is RGB colored with overlaid 1-foot aerial imagery.*

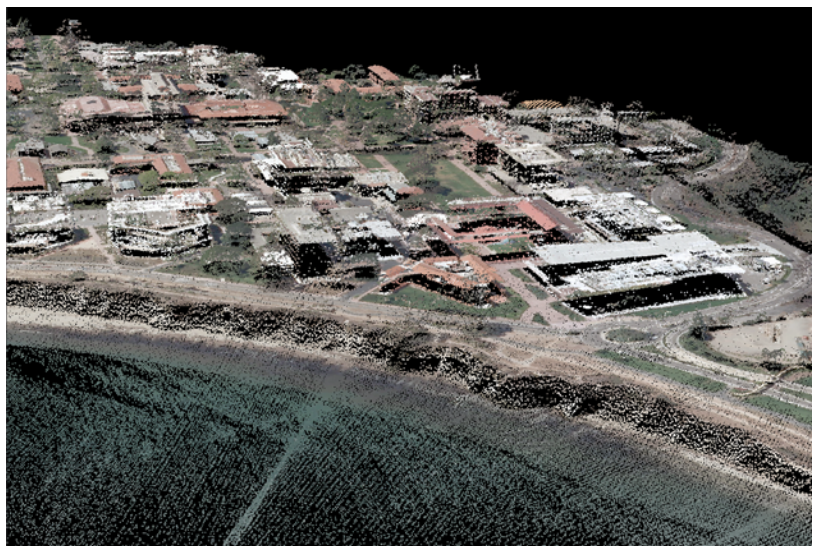


Figure 2. A monochromatic 3-D point cloud scene of a section of UCSB campus (acquired in 2012 with a Riegl LMS-Z420i terrestrial lidar scanner). Trees can be seen in high detail, with individual leaves resolved at cm-level resolution. The point cloud (11 million points) is rendered through a WebGL enabled browser, allowing the user to pan, rotate, and “fly through” the scene in real time. This demo makes use of the OSGJS javascript library; similar functionality can be found in other 3-D web mapping frameworks (OpenWebGlobe, ReadyMap, etc). <http://scigeo.org/applets/>.

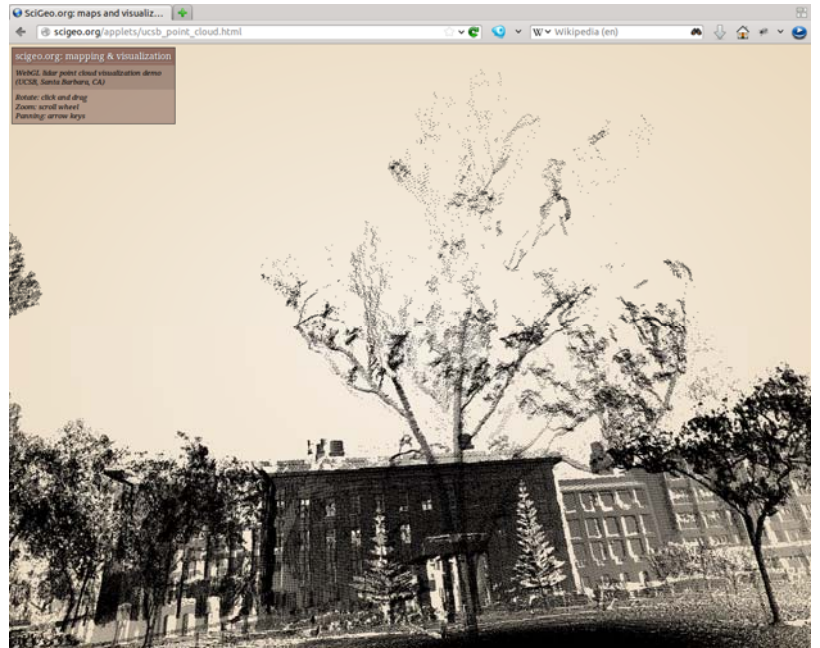


Figure 3. A 3-D point cloud scene of a campus office acquired with an inexpensive, portable Microsoft Kinect sensor (\$130 USD) over the course of 2 minutes. Such devices showcase the possibility of 3-D enabled volunteered geographic information (VGI).



Utilizing Mobile Devices for Sensor Networks

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My position for this meeting takes advantage of the global proliferation of mobile devices (e.g., phones, tablets, mini-PCs) combined with internal and external (via Bluetooth and USB) sensors. Both today's and yesterday's mobile devices are powerful computers connected to the Internet via cell networks and WiFi. They are plenty capable for monitoring, measuring, and responding to environmental factors such as air quality, temperature, pressure, and humidity. All sensor data (including GPS location) can be uploaded in real-time using 3G/4G networks and/or WiFi to a web SaaS for mapping, visualization, graphing, analysis, and data download. Whenever there is a loss of connectivity, data is stored locally on the device and uploaded immediately upon the return of connectivity.

Some scenarios and use cases require regular intervals of data collection (e.g., every 10 seconds or every 15 minutes) such as asset tracking or remote environmental monitoring. Other scenarios require responses based on critical thresholds of sensor values, e.g., send me a text message when the temperature goes below 36 degrees Fahrenheit or when Volatile Organic Compounds (VOCs) or CO₂ reaches a level higher than 2000 ppm. Android devices are easily capable of all of this plus a lot more that you can imagine when you start thinking about what sensors are available and the connectivity of a phone.

Valarm is an Android app currently available that does what is described above. It is compatible with a variety of sensors and has an integrated web SaaS (Valarm Tools: <http://tools.valarm.net>) where all sensor data is uploaded for mapping, visualization, graphing, data download and analysis. Combined with any power source (e.g., solar power, wall, vehicle accessory port) Valarm provides affordable remote environmental monitoring, mobile data acquisition, and asset / fleet tracking.

Currently supported sensors include, but are not limited to:

- Motion / acceleration
- Maximum speed
- Maximum range
- Distance to target
- Ambient light
- Microphone/audio
- External power
- Interval timer
- OBD2 (vehicle speed, engine RPMs, coolant temperature, and throttle position)
- Ambient temperature

- Relative humidity
- Barometric pressure
- Electrical resistance (used for water levels, flood alerts, potentiometers, gases, switches, soil moisture, leaf wetness, force-sensitive resistors, photo-resistors, and any sensor which operates by altering resistance)
- Air quality (CO₂ and Volatile Organic Compounds, VOCs)

Smart cities and campus are excellent scenarios for Valarm's capabilities. All of the sensors and other networks needed to enable smart campus services are already available and working with Valarm: Android, USB & Bluetooth sensors, GPS, WiFi, 3G/4G cellular networks. Tracking transit vehicles is one example where buses and public transit resources can be shared with the public (e.g., where is the bus right now). However, at the same time these vehicles can use Valarm to gather air quality data (e.g., VOCs) such that you and the public will be able to create pollution maps in real-time and decide where and how you want to travel based on current conditions.

All of the historical Valarm mobile sensor data can also be downloaded and analyzed by researchers to examine trends and understanding diurnal and seasonal factors. What is the air quality (VOCs & CO₂) of the campus during the day vs. at night? How about noise, light, and dust levels? Inside buildings and outdoors these sensors alert you to the presence of water and flooding. How about a gas leak? Based on real-time indoor air quality (iAQ) conditions, Valarm can not only send alerts but also trigger a switch to ameliorate the situation, i.e., open a window and/or turn on a fan. Campus gardens, agriculture, hydroponics, viticulture, and other similar scenarios also benefit from Valarm's real-time remote environmental monitoring. Temperature, humidity, and barometric pressure can be gathered at regular intervals to perform studies on mildew and mold in plants (correlated with humidity values) and also predict plus avoid plant damage or loss due to extreme cold or heat. Instant alerts also let you and/or the researcher know when action needs to be taken to prevent an undesirable situation.

Smart campus databases and resources also contribute to teaching and research opportunities for students and faculty. Faculty can ask students to use Valarm for affordable mobile data acquisition. Students then gather geotagged sensor data with a mobile device and combine the data with additional VGI then bring the data into a GIS for further analysis in 2D and 3D.

A recent example of Valarm being used for research is from Summer 2013 when Valarm was used to assess biodiversity while learning about the environments and behavior of insects and bees. This was a collaborative research project with the Page Museum at the La Brea Tar Pits, the Entomology Department at the Los Angeles Natural History Museum, and the BioSCAN biodiversity project. Valarm units were deployed to help this research and remotely monitor the micro-climate at multiple bee hotels in the Los Angeles area. The goal of the project is to assess biodiversity in local leafcutter bees (*Megachile*) and bee nest cell construction. More information on this and other uses is available on Valarm's blog at www.valarm.net.

Valarm gains an advantage over other sensor network technologies by utilizing commodity hardware and not needing any custom development, every piece is already widely available around the world. The mobility and flexibility of using phones, tablets, or any Android device is another benefit. Mobile devices are only becoming more affordable yet they are powerful, connected, compute-capable, and sensor compatible, which is something Valarm takes full advantage of in order to let anyone in the world “Monitor Anything, Anywhere™.”



Figure 1. The Valarm app supports a variety of internal and external sensors (via USB & Bluetooth) for remote environmental monitoring, mobile data acquisition, and asset tracking.



Figure 2. The Valarm app is integrated with the <http://tools.valarm.net> website where you can perform mapping, graphing, analysis, and download your sensor data.

Making the Business Case for the “Smart” Campus: Using Geo-spatial Data and VGI to Support Transformational Leadership

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Context

The historical evolution of the American university has always been shaped by high minded ideals of knowledge acquisition for its own sake, balanced with pragmatic concerns about acquiring practical and marketable skills. At present, over 21 million students are enrolled to attend one of over 4500 institutions of higher learning in the United States. Most of them are in pursuit of academic credentials that can lead to gainful employment. Yet, the higher education system is severely challenged by declining public investment, soaring costs related to employees’ retirement and health benefits, and escalating student debt. As the nation’s universities and colleges experience a crisis-induced transformation, it seems prudent to make a business case for just about any issue that we want our campus leaders to focus their attention. In this position paper, I intend to make three linked arguments – first, that addressing the issues of sustainability and human-induced climate change is one of the most dominant challenges of our time; second, that our colleges and universities are collectively well positioned to address these challenges by using their physical settings and sites for pragmatic interventions in addition to their more conventional contributions in the areas of research and teaching; third, that the potential of the use of geospatial technologies to facilitate innovative decision-making about sustainability and climate change at the campus level remains largely untapped. I will conclude by describing some opportunities for institutional collaboration and action around these issues where the engagement of industry and community partners can make a meaningful contribution. In my presentation, I will discuss the specific case of Portland, Oregon.

Why Sustainability, Why Now?

The impacts of rapid population growth and human-induced climate change have made addressing sustainability one of the more pressing and challenging issues of our time. In the literature and in accepted best practice, addressing sustainability often means considering the triple bottom line— balancing economic, social, and environmental considerations to assure smooth operations within an organization. For institutions of higher learning, championing the sustainability agenda appropriately includes addressing the educational and research mission as well. Beyond the philosophical and moral imperatives to consider sustainability, the threat of human-induced climate change impacts on our cities and communities challenges leaders across

all sectors to work on practical and measurable interventions. In a recent study of 1000 CEOs across the world that included 27 industry sectors in 103 countries, 29% of CEOs regarded climate change as one of the most important sustainability challenges for the success of their businesses while a full 67% of respondents indicated that business was “not doing enough” to address global sustainability challenges (Accenture, 2013). One of the main points made by the business sector is that there is a need to address the issue of scale— to understand the magnitude of problems, to respond appropriately, and to move from incremental achievements towards “a new global architecture” to balance the complexity of the challenges. Other concerns raised by the business sector include the need for intelligent infrastructure that supports collaborative decision making and supports a serious multi-directional dialog with a variety of stakeholders. Enlightened business leaders recognize that they need to engage government regulators, policymakers, industry peers, consumers, NGOs, investors, shareholders, employees, and labor unions to achieve sustainability goals and address climate change and associated challenges.

What is the Role of the University in Promoting a Sustainability Agenda?

Universities and colleges have always been centers of innovative thinking. The American model of the land grant/extension service program developed in the late 19th and early 20th century firmly established the ideal of extending the knowledge and expertise present within the academy in service of the region. While the traditional extension programs had many positive benefits such as providing expertise and guidance to improve farming practices, they also created a hierarchical relationship that sometimes devalued local knowledge and experience. Yet, the land grant/extension service model, supported through government funding fundamentally changed rural America. More recently, the student protests and activism of the 1960s helped foster university-based design/planning centers that focused on addressing community concerns. These efforts, largely urban, developed innovative models of community outreach and engagement to harness resources available within the university to respond to the needs of the neighborhood surrounding the university. The community-university partnership model, also supported with federal funding, has helped to shape urban America. In the 21st century, there is an urgent need for universities and colleges to provide expertise, experience, and guidance to address sustainability related challenges. Both models of university-based engagement with communities can be usefully deployed to address sustainability challenges and in fact many universities are doing exactly that. However, sustainability related activities and investments in universities and colleges are largely uncoordinated. The physical configuration of a typical American university campus with multiple physical locations and an increasingly emergent online presence further compounds this problem. As our populations become concentrated in urban areas, urban serving universities, in particular, have to directly confront these challenges through direct services provision, training, and capacity building. Universities can also serve as test beds for innovative ideas that are backed by “good” science and make the science accessible to support individual and community empowerment. Lastly, the technological

and data infrastructure now allow for citizen science efforts in the area of addressing sustainability challenges that offer great promise to support a distributed and decentralized approach to problem solving.

Campus Sustainability – Modeling and Embedding Best Practices

According to Ferdig (2007), “sustainability leadership reflects an emerging consciousness among people who are choosing to live their lives and lead their organizations in ways that account for their impact on the earth, society, and the health of local and global economies.” (p. 26). In the context of the American university setting, the university is made up of at least three distinct interest groups, administration/staff, faculty, and students. Thus, leadership on a university campus to address sustainability challenges almost always requires conversations and processes of work flows that are agreed upon through consensus before any actions can occur. Thus advocacy becomes an integral element of leadership on university campuses. In addition, university and campus leaders cannot use a narrow interpretation of sustainability in energy/environmental terms alone and must consider social sustainability as well. There are many successful models that support best practices in addressing sustainability challenges.

The American College and University President’s Climate Commitment (ACUPCC) is an alliance of college and university presidents who have voluntarily chosen to use their positions of leadership to create comprehensive climate action plans using collaborative and transparent processes within their own institutions. The goal is to achieve climate neutrality (net zero) in specific campus operations, promoting education, research, and development of specific solutions to address climate change challenges and to publicly report on their progress. At the end of 2012, 677 universities have signed the ACUPCC commitment directly and indirectly engaging over 6 million students. 1583 GHG inventories and 465 climate action plans have been submitted and these plans can be evaluated and monitored by the public. The ACUPCC engages all sectors of the higher education spectrum from public to private, from community colleges to research intensive universities, and in all 50 states.

The Sustainability Tracking, Assessment, and Rating System (STARS) developed by the American Association of Sustainability in Higher Education (AASHE) is a reporting framework designed by higher education professionals for higher education institutions to measure and manage their sustainability performance. STARS is designed to:

- Provide a framework for understanding sustainability in all sectors of higher education;
- Enable meaningful comparisons over time and across institutions using a common set of measurements developed with broad participation from the campus sustainability community;
- Create incentives for continual improvement toward sustainability;
- Facilitate information sharing about higher education sustainability practices and performance;
- Build a stronger, more diverse campus sustainability community

(Source: <https://stars.aashe.org/pages/engage/stars-overview.html>)

In addition to these comprehensive efforts, there are many individual efforts ongoing at several university campuses. In my presentation I will discuss the ongoing work of the Urban Sustainability Extension Service at Hunter College and the work of the Institute for Sustainable Solutions at Portland State University. If the participants at this meeting are in agreement with my view that what can get measured can get managed— in other words, that assessments and tracking are incredibly useful to support the cause of sustainability, then the ACUPCC's efforts and the STARS assessments must be applauded and supported by our GIScience community and our expertise and experience must be linked within these reporting efforts.

How can Geo-spatial Data and VGI Support These Efforts?

The ACUPCC Climate Action Plans and the STARS rating systems both track different activities that occur on a university campus. In STARS, there is a focus on Academics; Engagement (campus and public); Operations (including building management, grounds, dining, energy, purchasing, water, waste, and transportation); and Planning and Administration. Similarly the ACUPCC plans focus on investments in research, curriculum/teaching, and community engagement in addition to measuring the impacts of new construction, transportation, and other campus operations like purchasing. Both these systems are simplified to make reporting and data collection less onerous. Yet, they focus on a static approach to data collection, measuring information in specific reporting time intervals. In addition, both these efforts seem particularly void of spatial thinking and reasoning.

I believe it would be an interesting challenge to explore how the ICT and visualization experts assembled at the Spatial Campus meeting can engage with efforts from the higher education community to develop a more robust data collection schema into the data collection efforts. Engaging citizens (students, faculty, employees and administrators) as participants in the data collection can be a big data challenge and an opportunity. It will be intriguing to explore how the static data collection protocols can be transformed to be a more time-sensitive data collection and analysis effort. It would be reasonable to expect that protocols be established to support open source data tools used and that a transparent data infrastructure is adopted. In addition, there will be a great need to support data and information literacy across the university and facilitate protocols for data ownership and ethical data sharing including providing opt-out options for people/groups who can choose "not to be sensed" (Rockefeller Foundation, 2013).

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Four Puzzle Pieces for Advancing the Spatially Enabled Smart Campus

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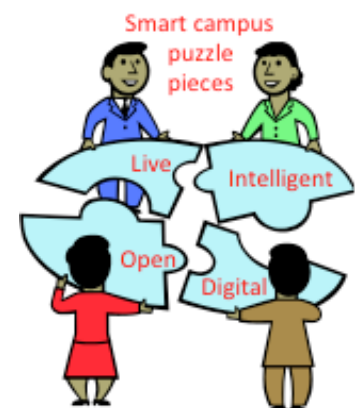
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Can cities be smart enough without being spatially enabled? The answer is undoubtedly no but it is not obvious. To be considered as spatially enabled, a community (city, local government, society, university), must first consider location and spatial information as common goods, and then make them available in order to stimulate innovation. Therefore, in order to become spatially enabled, three conditions are required. First, community members have to be “spatially literate.” Secondly, spatial enablement requires a conducive environment to open and share spatial data. Last but not least, there is no possible spatial enablement without shared and unified geospatial standards (Roche et al., 2012). For its part, the idea of the Smart City resulted from a very aggressive strategy developed by Information Technologies giants, such as IBM or CISCO, it was quickly taken up by researchers from various disciplines. Some of them see it as an opportunity to rethink the notion of urbanisation with a more systemic approach, reintegrating the concept of sustainable development into urban context. Some others associate the idea of Smart City with an active commitment of citizens into urban innovation processes, thus overhauling city governance through open and bottom-up procedures (government, data). Finally, the others take this opportunity to advocate the fact that urban infrastructures based on the systematic use of information and communication technologies show greater efficiency.

Nevertheless, to date, no consensus has been reached from this proliferation of interests. In order to understand the concepts underlying the Smart City, we have focussed on what specialists had to say about it. I’m currently carrying out a meta-analysis from a corpus of 67 recent publications [24 peer-reviewed scientific papers, 23 studies published by private companies and 20 reports (uses cases or case studies) published by local governments (essentially cities)]. This corpus contains a total of 71 8923 words (33 542 distinct words). I do not intend to go into the details of the lexicometric analysis in progress; yet, I would like to use the preliminary results of this study to propose and discuss a draft framework for Spatially Enabled Smart Campus.

The proposed framework is based on the four puzzle pieces shown on this figure, which need to be properly organized by university stakeholders in order to advance campus development. For implementing and maintaining each of this puzzle parts the role of information and geospatial technologies is crucial. A campus could be seen as a small city (e.g., Laval campus: 50,000 people, 40 buildings and a 1.8 km² area). So in term of administration and infrastructure management (building; services: energy, water; BIM, transport . . .) the issue is very similar to



the one of a city. But the rationale of a university is very different: knowledge and universality are the core business of Universities.

1) The **digital campus** aims at efficiently operating an infrastructure based on communication and information technologies, networks and sensors so as to optimize campus' "routine" operations, which could be called campus Operation System. GISciences can support Smart campuses by dramatically enhancing this digital dimension, and in particular the university informational infrastructure. When the concept of digital Earth is for instance applied to campus contexts, it closely reflects this digital dimension. Indeed, ongoing work in the fields of SDI and big data offer possible methodological and technological solutions to support campus in the implementation of a digital model (e.g., a Lidar-based 3D model has been developed for the Laval campus to serve multiple applications). More particularly, and to use the words of Craglia et al. (2012), the next generation of digital campus will not be a single system but, rather, multiple connected infrastructures (related to various physical components of the campus: transportation, land organisation, BIM, as well as knowledge components: online and mobile courses, student services, research supports . . .) based on open access and participation across multiple technological platforms that will address the needs of different audiences (student, faculty (cross-disciplinary), citizens, etc.).

2) The **open campus** is a way to create methods of governance re-structured around informational infrastructures and open services/data, based on collaboration and partnership to improve the efficiency of the services provided to the university community (not only internal), especially in terms of knowledge transfer, scientific mediation, participatory learning . . . This "open democracy" dimension can benefit from the recent advances in GISciences. Indeed, the concept of open democracy is threefold: cooperation (transversality and partnership), participation (co-construction of public policy, consultation, debates) and transparency (open data and dataviz: use of images). GISciences are particularly relevant in terms of participation and transparency. For instance, they provide technological mechanisms and infrastructures to develop access and delivery (location-based and mobile) platforms for open knowledge and open course, ensuring their qualification (adding metadata and sharing students experiences) adapted to various audiences and enhancing readability through multimedia and (carto) graphic representations.

3) GISciences can also support the development of the **intelligent campus** dimension, that is to say of the social infrastructure and civic spatial engagement practices. Crowdsourcing and VGI, including location-based social networks (in Laval, the use of dedicated social medias are exploding, including as a new teaching tools), stand out today as key geospatial data sources indicative of the pulse of places. The connected campus community members, acting as active sensors, have the capacity to contribute even more efficiently to the spatial intelligence of campuses. Indeed, GISciences offer different types of potential support: the design of mobile positioning technologies centred on the individual, and providing more user-friendly interfaces for various applications (M-Learning, serious gaming as the one that has been developed in my department for the green campus challenge . . .) or teaching approaches to improve community

members' spatial skills and provide them with spatial thinking advanced abilities so that they could use spatial analysis approach in various discipline.

4) A Smart campus is a place where students should become citizens, where they could be part of renewing the forms of active citizenships built on the participatory involvement of all community members, with a concern for innovation. The **live campus** dimension refers to a way of seeing university campuses as living/fab labs that are continuously being reshaped (adaptive to change). In this context, GeoDesign, with a big D (Goodchild, 2010), as part of GISciences, provides innovative, creative, deliberative, uncertain, multi-actor, multi-scale and multi-thematic methods and tools to design smart campus and impact on their physical and "senseable" structure (e.g., the TEDxCity2.0 lab we have recently organized across the Laval campus with external partners or the GeoHack meetings that have started in the campus in order to improve community members' spatial skills and help them to be more efficiently involved in its design.

Does a “Smart Campus” Create “Smart People”?

From Smart Cities to Smart Campuses—Supporting the “Campus Citizens”

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I have three simple rules to build a “Smart Campus”:

- Listen to your people.
- Make the invisible visible.
- Create experiences not services.

There is no doubt that there are major challenges that future cities will face, not least a huge increase in the populations living in urban areas. According to a United Nation report [1] every second the global urban population grows by 2 people. Therefore the urban population is expected to increase from 3.6 billion people in 2011 to 6.3 billion in 2050. In 2020 more than 700 cities will exist with populations of +1 million; today we have just 500 cities with populations of +1 million. The exploding urban population growth creates unprecedented challenges, among which provision for water and sanitation are the most pressing and painfully felt when lacking [6]. Cities cannot be sustainable without ensuring reliable access to safe drinking water and adequate sanitation. Therefore, many tech companies are investing in R&D to create ‘smart’ cities, with the goal of making our lives more efficient, better informed and hassle-free. Research estimates that \$16 billion USD will be spent annually by 2020 on core technologies in pursuit of this goal. A recent trend has been to develop the “Internet of things” that can sense, connect and mine a wealth of data about our cities, the environment and ourselves.

Our Intel Collaborative Research Institute on Sustainable Connected Cities¹ [4] is concerned with enhancing and changing how people live, interact and engage with cities. Our main goal is to enhance city sustainability and improve citizen well-being.

The Smart Campus an Incubator for a Smart City

While the interest in future cities and the future challenges are quite clear, the “millennium challenges” of future campuses still remain unclear. Will it be the fact that campuses will have “just” more students and less staff? Or more diverse groups of campus citizens, including many more guests or visitors connected through the Internet to the groups and people working and living on the campus? It is safe to say that each campus will have a unique set of challenges that need to be addressed. Campuses are far more diverse than cities and harder to cluster into categories than cities.

¹ www.cities.io

During the specialist meeting we would like to share our views (coming from a city perspective) and best practices that we learned and researched within our center from a computer science background, particularly focusing on human-computer interaction aspects (HCI) to improve the **campus experience** of future campuses. We will focus on the following three aspects:

1) The “Campus Citizens” are key to the success of any smart campus project.

Do not listen to McKinsey & Company²—listen to your people. Consultancy companies have great plans in their drawers— plans for future cities and also campuses based on data. As outlined earlier, our perspective in the Sustainable Connected Cities Institute is human-centered. We have wide-ranging expertise and background in user experience, interaction design, ethnography and ethnography, together with research in the built environment, commerce, engineering, anthropology, the arts, and social psychology. We also work as interdisciplinary teams (with people from computer science, designers, ethnographers, and psychologists among others) to make a real change to enrich and extend city dwellers lives. This fits with the vision of Bell [1] of computers not just acting on our behalf and anticipating what we want but also enabling people to be more creative, using state of the art computer technologies and toolkits. Therefore we think it is crucial to focus on the “campus citizens” and their needs. A campus comes alive because of the students, faculty, administration, service and visitors. It should be more than “buildings controlled by a fancy dashboard.”

2) Misbalance between input and output

Many claims have been made about the potential benefits of embedding smart technologies in cities that connect the infrastructures with our public spaces, streets, homes, mobile phones and even our clothes could be tested before on university campuses to see possible impacts and effect. We noticed that there is still a huge misbalance between this “input” and the “output” back to the citizens. We will share our best practices and examples how ICT can change and impact the behavior of citizens (city and campus citizens) by connecting them to the “invisible data streams” of the city/campus as we for example did with the Tidy street project [2]. Others have also successfully presented various project e.g. MIT’s Senseable Cities group³. We will reflect on the list of services, output interfaces and ways how people can interact with the data streams that have the potential to transform and shape a campus, especially having the role of space in mind.

3) Striving for efficiency?

Besides being a mini-city, each campus has some unique characteristics that need to be taken into account. By placing increasing numbers of sensors in all kinds of places that can be monitored, we could collect real-time data about how our utilities are faring, our transport is moving, our energy is being consumed, where things and people are and what they are doing,

² http://www.mckinsey.com/insights/urbanization/how_to_make_a_city_great

³ <http://senseable.mit.edu/>

with the hope to achieve a greater understanding of how our “places” work, what is needed to make them work even better, and how to maintain them more efficiently when something breaks down. Smart grids are being deployed in the background aiming to support the rapid and effective contingency and capacity planning. This is “just” the homework that we need to do. These enabling technologies are only the foundation for a successful future campus. We believe that research on smart campuses should not strive for this super-efficiency of the underlying technology. We argue that it is equally important for the “campus space” to consider the impact of new campus technological developments on quality of life and create an atmosphere that will help researchers and students conduct high quality teaching and research.

The accumulation of vast amounts of campus sensor data should not become overwhelming, making people feel disempowered or even disengaged. It should be designed to support the main role the space plays in their lives: **education, research**, and creating a **pleasant campus experience**.

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Spatiotemporal Visualization of Local Sensor Networks for Action on Campus

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The number of technologies that provide extremely detailed information about the operation and activities on a college campus are burgeoning. From environmental monitoring of indoor air quality to energy use to traffic flow to building access, the volume of spatio-temporal data that is being captured is overwhelming. Given the complex, multi-dimensional and granular nature of this data, it is often difficult for campus managers to make sense of it. Taking this voluminous data stream and extracting the signal from the noise and then presenting that pattern in a way that is actionable on the part of the manager are critical steps in advancing the spatially enabled smart campus.

Spatiotemporal visualization as a research and commercial activity has existed since the invention of computer cartography. Many techniques including map sequences, map animation, exploratory spatial data analysis, multi-dimensional mapping, and scientific visualization have been explored by geographers, cartographers, computer scientists, artists, and technicians at leading software companies. Best practices, industry standards, and entire computer graphics libraries have been developed for the display of spatiotemporal information, some more compelling than others.

In the last decade or so, the rise of a particular type of visualization bears closer—the dashboard. Dashboards, or sometimes expanded to business intelligence (BI) dashboards, is “a data visualization tool that displays the current status of metrics and key performance indicators for an enterprise (Rouse, 2010).” Just as the dials and indicators on a car dashboard give the driver information about performance of the vehicle’s components, so too does a BI dashboard give information about the performance of a business unit, often complete with red, yellow, or green indicators tied to a predetermined performance goals. While the visualization techniques used in these BI dashboards are not new (and often not particularly sophisticated), they are worthy of examination because of their focus on a) actionable intelligence, b) the ability to drill down into the data patterns in an active way, and c) the near-exclusion of the geographic dimension of the data.

Salisbury University in Salisbury, Maryland recently completed the installation and testing of a GIS-based indoor air quality and energy use monitoring system for our newest building on campus (Esri, 2013). This system, named SpatialMMS and created by Spatial Systems Associates of Columbia, Maryland, pulls data streams related to temperature, humidity, CO₂ levels, and energy consumption directly from the building automation system and displays them on maps of the building space as well as time-series graphs. These visualizations are available to both campus facilities managers and visitors to the building through a kiosk system. While the

visualizations that are built into the system are functional, they are not particularly compelling or sophisticated, nor are they actionable. However, my team at the Eastern Shore Regional GIS Cooperative at Salisbury University have been developing and refining “spatial intelligence dashboards” that could be used to reanimate the data from our campus building sensor network and achieve a higher degree of understanding and insight. Examples of our open-source, cross-platform data visualization tools are:

- MD Dept of Labor, Licensing and Regulation Workforce Dashboard
<http://www.dllr.state.md.us/workforcedashboard/>
- MD BayStat, Causes of the Problems and Solutions
<http://baystat.maryland.gov/sources2.html>
- Caroline County (Maryland) Department of Emergency Services
<http://www.esrgc.org/dashboards/carolinedes/>

I believe that we have just scratched the surface with regard to the extraction of local sensor network data for compelling and actionable visualizations. Harnessing open-source mapping and graphing libraries for enabling a spatially-aware smart campus is likely to be an area of exploration for some time to come.

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Advancing the Spatially Enabled Smart Campus

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with

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Georgia Tech is located on a 400-acre urban campus in mid-town Atlanta. It is a true global community of over 20,000 students, 6,000 faculty and staff. The university has grown double in size in the past twenty years. The growth trend is expected to follow the same trajectory in the near future. The institute's strategic plan "Georgia Tech 2035" prominently features Georgia Tech's commitment to build a sustainable campus from multiple aspects. This places an enormous pressure on administrators in planning, designing, building and operating the campus.

To plan for the future we need to understand the current conditions. What are we doing in this regard? What practices are in place? What practices are being developed? How will Georgia Tech look like in the year 2025 and beyond? Will it grow horizontal, vertical, or consolidate? We are seeing a paradigm shift in the higher education landscape. Will the campus of 2025 resemble the campus of today? How do we see the future and build for it? Do we need the same amount of space per student for classrooms? Or do we need technological solutions that enable student participation from wherever? How do we accommodate increased space requirements for sophisticated research undertakings? What about other support infrastructure demands? These are all common questions that many university campuses need to address and these are inherently spatial issues.

As part of the upcoming campus master plan, we are developing spatially enabled tools to visualize different scenarios and develop metrics that will allow the alternatives to be compared for the campus of the future. These tools will be used to solicit input from stakeholders at various stages of the planning process, build support for the plan and communicate the results of the planning process when the plan is finalized. The use of spatially enabled digital models and databases will allow the plan to be monitored and updated as parts of it are accomplished and to incorporate new opportunities as they arise and are added to the plan.

We expect to develop metrics on sustainability and energy use. Energy models have been developed for more than 30 buildings on campus. New constructions and major renovations have state of the art sustainable systems with sensors embedded in them. Current and future capital planning projects will have as deliverables the as-built models. These will be used as a base for facilities management and operations. We will incrementally convert the campus facilities to building models from 2D to 3D spatial models. Laser scanning of indoor spaces is

being done for newer spaces yielding accurate 3D representations of interior spaces. These new capabilities are just being formed and models will serve as the platform for future assessment of inventory, planning new initiatives, and for maintenance and operations. Developing both standards for BIM modeling and protocols for data transfer and integration with spatially enabled smart databases are critical. Real-time energy usage data gathered from across campus buildings and facilities can be displayed to stakeholders through a dashboard like platform potentially influencing to lower energy consumption.

Georgia Tech has greatly reduced its municipal water consumption during the past decade. More than 40 different water harvesting systems with a combined Cistern capacity of over 2.5 million gallons have been implemented. Harvested water is used for landscape irrigation, athletic fields, and for flushing toilets. These water harvesting systems have been mapped and integrated in to the campus spatial database for visualization. Smart sensors that monitor water inflow and outflow from the cisterns, sensors that detect leaks along irrigation channels, sensors that read weather forecasts to auto adjust irrigation schedule before rain events occur are some potential areas that would greatly enhance sustainability goal.

True to its sustainable practices, Georgia Tech recycles more than 1,300 tons of solid waste each year at a cost of well over a million dollars per year. Recycling assets of all types from large roll offs to dumpsters to small recycling containers are spread across the campus. Outside contractors are tasked to empty these containers at a fixed schedule. Perhaps smart sensors can help optimize solid waste recycling operation by triggering a demand driven service request from the contractor for a potential cost savings. Operations can be monitored through spatially enabled campus dashboard.

Parking is increasingly becoming an issue at Georgia Tech. More than 13,000 parking spaces cover the 400 acre campus with several multi-story parking decks to surface spaces. Sensor enabled parking systems that tell the campus community about available parking spaces on a specific lot and a spatially enabled dashboard application that directs someone to the space will be an ideal solution.

How to present and convince campus administration about the merits of spatially enabled campus? With shrinking budgets these days, specifically public institutions like Georgia Tech every dollar spent is looked at very closely. We need to create compelling cases to get support from administration. A simple case in point is our recent tree inventory. In alignment with its sustainability efforts, Georgia Tech has set an aggressive 50% canopy goal in its master plan. Facilities and landscape services needed a reliable tree inventory to keep track and monitor progress of canopy coverage towards stated goal. This business driver alone was not enough to get resource support from the administration for a complete inventory. In the recent past, number of trees of varying size and age has fallen around campus causing damage to property. Luckily no people were harmed in these incidents. Campus risk management wanted to know if landscape services were aware of health of fallen trees. Data was lacking to satisfactorily answer the questions. This provided an opportunity for a complete tree survey of the campus. In addition to the aesthetic beauty and canopy it provides, we wanted to quantify environmental

benefits of these trees such as carbon sequestered, rain water mitigated, and pollution removed. Storm water engineers do not adequately consider trees in their design solutions. There is a research gap at the present time. We took the opportunity to devise a spatially enabled smart database that could cater to the business needs as well as the research needs. The combined multifaceted benefits enabled us to garner support from the administration. The spatially enabled inventory database of 11,500 trees with about 42 different attributes for each tree was completed successfully last year. The inventory is being maintained continually. Georgia Tech is positioning itself as an active living and learning laboratory in this effort. We are also in the process of joining hands with US Forestry service and regional universities to develop a regional database of tree inventory that supports eco analysis and multitude of related research objectives. The tree inventory database is fast becoming a most commonly used database for planning, operations, and research purposes. We believe that this is a good example of starting small with a bigger and deeper reach. We are planning for sensor deployments on selected significant trees on campus. For us, this would be one component of a complete dashboard solution.

Resource crunch is real and it is here to stay. The new normal is doing more with less. We need innovative solutions for complex issues that face us. Platforms for building technology solutions are increasingly becoming affordable. As researchers and practitioners of geospatial technology it is our role to look out the horizon and develop frameworks, standards, specifications, procedures, and workflows to realize a spatially enabled smart campus. It is going to be enabling world of sensors and it is going to grow at unbelievably fast and has a high potential for never before seen efficiencies.

We envision scenarios where the Virtual Georgia Tech is an immersive and interactive portal that supports navigation through the campus and an open-ended range of capabilities, built up incrementally that relies heavily on spatially enabled smart platform. Time is now for smart campuses.

Georgia Tech is fortunate to attract the best and brightest students. We just need to educate them to think spatially. To enable desired solutions we need a good framework, we need sound data models and well defined procedures. It must just work.

Spatially Enabled Smart Campus

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What is this *space* whose relevance is posited by the notion of a *spatially* enabled campus? The position put forth here is that different notions of space lend themselves to *operationalizing* distinct, yet complementary, elements of the smart[er] campus. I would like to highlight three such spaces, each emphasizing a different manner of positioning campus-related phenomena, namely in reference to (1) physical space, (2) attribute space, and (3) conceptual or knowledge space. Though not discounting their value, I will here not concern myself with certain dominant approaches, like social network spaces.

Campus in Physical Space

Though I want to primarily draw attention to some alternative spatial approaches, some of my recent work in human mobility analysis (Figure 1) has direct bearings on possible investigations of temporal patterns of campus demographics and resource use and could be deployed to that end, given almost ubiquitous WLAN access on many campuses.

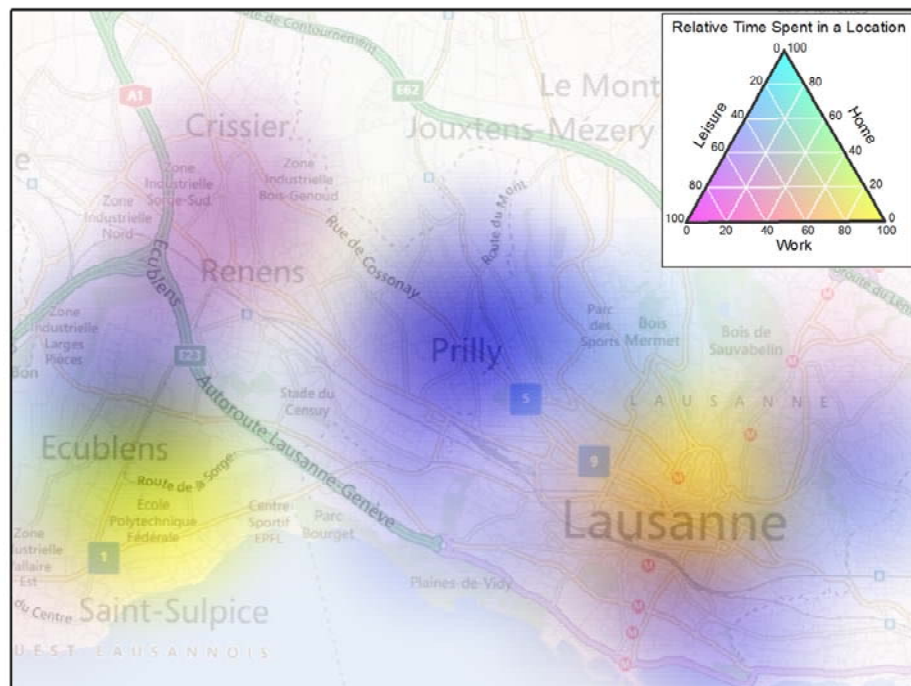


Figure 1. 2.4 million cell-phone locations, captured via GPS and WLAN access and aggregated to reveal dominant temporal patterns of occupancy. Notice the campus of EPF Lausanne in bottom left corner. (from Skupin 2013)

Campus in Attribute Space

Higher education campuses are distributed sparsely in physical space, separated by tremendous geographic distances. Meanwhile, compared to nearby surroundings, a campus environment will often be markedly different, in terms of socio-economic composition, architecture, and governance. All this lends itself to an *insular* approach to representing this social construct, which is for example manifested in such views as "the campus as city". Conversely, the lived experience of its inhabitants is however implicitly (through similar experience) and explicitly (through networked communication) shared across hundreds of campuses, forming a special community of shared interests that bridges geographic distance. Unless *city state* is a more apt metaphor, I would argue that placing campuses in attribute space – defined by the multitude of characteristics of the natural and built environment and its inhabitants – would support a very different representation of campus environments. This could be done through a mix of computational and visual means, leveraging authoritative data sources (Skupin and Esperbé 2011), individual experience (Burns and Skupin 2013), and social media artifacts. Among the applications of such an approach is the data-driven delineation of "best practices" such that the uniqueness or exchangeability of the specific campus context can be usefully elaborated. I would of course advocate an integrated approach to representing campus-related phenomena in physical *and* attribute space, also in support of improved understanding of the on-campus/off-campus interface.

Campus in Knowledge Space

The power of a spatial viewpoint can extend to a campus' ultimate *raison d'être*: the development and cultivation of *knowledge*, as evident in the variety of educational, research, and administrative practices that campus inhabitants are engaged in. To me, a campus that would truly be spatially enabled would also be one in which spatial concepts (e.g., size, shape, region, scale, etc.) are operationalized in order to make evident, communicate, and relate the complex knowledge structures of diverse domains. Though much of my work during the last decade has dealt with that issue, a just-finished research project (Ahearn et al 2013) has opened up numerous new directions, all of which point to the power of a spatial perspective, from performing n-dimensional *overlays* (Fig. 2) to the tracing of educational *pathways*.

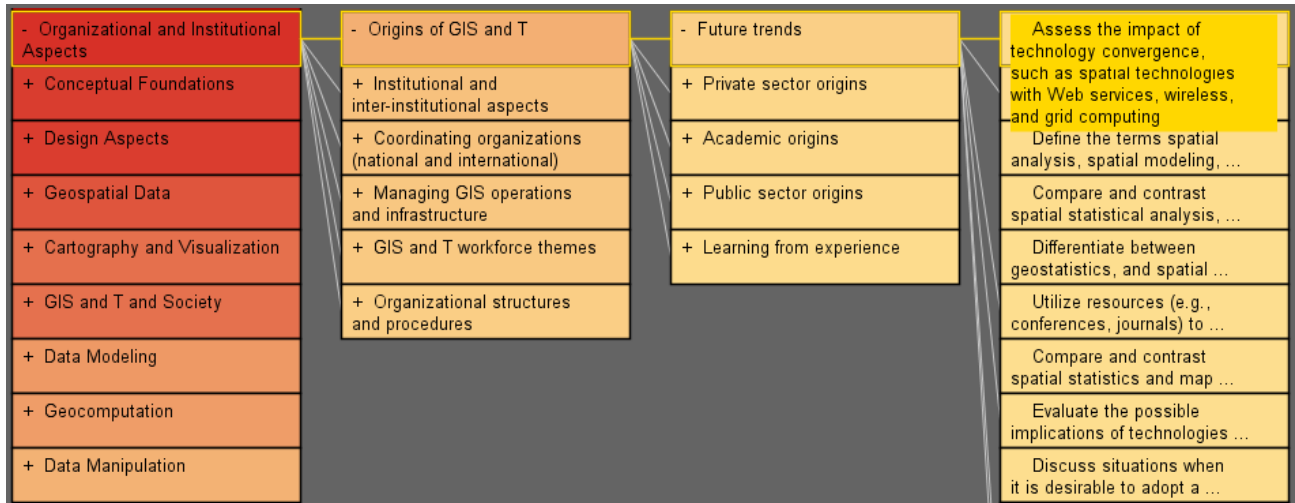


Figure 2. *The CFP of the Advancing the Spatially Enabled Smart Campus Specialist Meeting projected onto the hierarchically structured GIS&T Body of Knowledge. Darker colors and higher vertical position indicate a stronger match of the Specialist Meeting to the BoK. The highest matching elements at each of the four levels of the BoK hierarchy are highlighted.*

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Experiences from Designing a Campus Flood Management Collaboration System

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After going through a devastating flood where more than 20 campus buildings sustained damage in June 2008 due to flooding, and the Arts Campus was especially hard hit, the University of Iowa Facilities Management (FM) organization was looking for new ideas and systems to help ensure the University would be better prepared for future flood events. Our GIScience research group developed a web-based flood management and collaboration system where flooding, building vulnerabilities, and evacuation recommendations can be tracked and visualized in real-time, along with action decisions by campus leadership that are input and displayed in addition to the system recommendations. The real-time and predictive capabilities of the model affords more time for FM teams to respond to at-risk situations, deploy strategies for erecting flood barriers where needed, evacuate building contents, and plan possible road and building closures. The timely evacuations of individuals from natural hazards, is a topic that has engaged GIScience researchers (see e.g., recent research by Horner et al. 2011, Shekhar et al. 2012).

Working with FM to develop the system, was very much a collaborative effort. We had regular meetings with different stakeholders and tested the system several times in tabletop training exercises to make sure the kinds of information needed in a flood emergency were being provided by the system. An evaluation of the system outputs (e.g., evacuation recommendations) using historical flood data has also been carried out. The main elements of the system are: a web-based flood mapping and building vulnerability viewer that captures two possible modes, with full mitigation (e.g., flood barriers) in place, or with no mitigation in place (i.e., worst case scenario); and an interactive building status viewer where campus decision-makers can input and potentially override any recommendations made by the system regarding building evacuations (Figure 1).

The flood mapping and building vulnerability component involves a vulnerable buildings knowledge database that provides details on the location, elevation, and other properties of buildings in the floodplain, as well as the length of time needed to evacuate the building. Real-time and forecast hydrologic data is collected from the National Weather Service (<http://water.weather.gov/>) and includes hydrologic data consisting of stream gage discharge and stage information. This information is stored in a dynamic database and updated regularly. Historic, real-time and forecasted inputs are incorporated in the model, providing a temporal perspective for flood management. A real-time report is generated for system users as well as a forecast report. A web map viewer displays the campus, flood boundary, vulnerable buildings, and evacuations recommended based on system parameters in real-time. In this way, the spatial inputs (the flood inundation layers) are linked to temporal components (flood forecast information), and the space-time progression of risk to campus buildings is made available for

the broad range of campus decision-makers (FM, risk management, public safety, campus housing etc.) that work together when flooding threatens the campus.

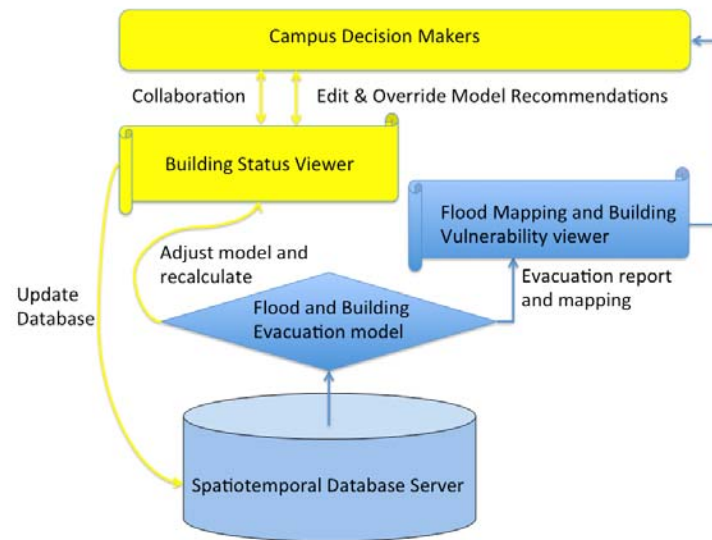


Figure 1: Elements of the flood collaboration model (J. Fan).

The direct input of decision-makers is what makes this system especially interesting and relevant. Campus leadership uses the maps and reports generated by the system as a basis for their discussions and planning during a flood. Based on a number of factors, however, decision-makers may decide not to follow the system recommendation exactly, for example, delaying building evacuations that the system suggests should begin, or putting up barriers even before the system recommends the construction of floodwalls. An interactive and editable webpage in the system allows for such actions to be added to the system and the map display. In this way, everyone can see what is forecast and what actions have been taken, and a useful record of the decision-making process is captured and stored for post-hazard analysis.

While working with the Ulowa FM team on the flood model was our first effort with smart campus applications, the outcome is that they are ready to form campus collaborations and more interested in what geospatial technology allows them to do. Clearly there are many opportunities relating to smart campus design and innovation. We are now exploring how to extend our spatiotemporal database that includes many campus geospatial features, to also model student dynamics, such that campus decision-makers can have a more comprehensive awareness of the space-time patterns of mobility on campus to support management functions. Further extensions to the flood management system are likely too as it would be possible to incorporate user-generated content in the system. For example, if individuals send out tweets about water on roads in one part of campus, this information can be geocoded and added to the map viewer display, adding to the real-time road inundation and flood boundary information.

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Advancing the Spatially Enabled Smart Campus

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The “spatially enabled smart campus” alludes to two complimentary efforts—the spatially enabled society and smart cities. The spatially enabled society refers to advances in the management and organization of people, environments, and economies as a result of making location and spatial information freely available to people and businesses. It is intended that the availability of such information would encourage the development of creative goods and products (Rajabifard, Bins, and Williamson, 2007). The focus is on spatial data infrastructures. Smart cities, on the other hand, is a concept emerging from urban planning and urban design that takes into account six interconnected dimensions—smart mobility, smart environment, smart people, smart economy, smart governance and smart living. It is believed that sustainable economic growth and effective, efficient governance can be achieved by investing in social and environmental capital and infrastructures (Caragliu, Del Bo, and Nijkamp, 2009). The focus is on improving cities by leveraging new technologies. The spatially enabled smart campus, therefore, implies the merging of these two concepts in order to promote the broader goals of fostering creativity and sustainable practices. This would suggest that key players in this venture would likely include cognitive psychologists as well as architects.

While it is a useful exercise to imagine an ideal future smart campus given a blank slate, the reality is that student enrollment is continuously increasing on our current campuses, and existing infrastructure (both the built environment and spatial data infrastructures) cannot be easily cast aside. So how does the idea of a smart campus work with our current standards?

As university communities—students, faculty, and staff—become more diverse, consideration should be given to individual differences in spatial thinking (Hegarty and Waller, 2005; Newcombe and Shipley, in press). Spatial thinking is multifaceted involving the interrelated abilities of understanding space, representation, and reasoning. It is central to everyday decision making, communication, and navigation and is critical to success in the STEM (i.e., science, technology, engineering and mathematics) disciplines (Newcombe and Shipley, in press; Wai, Lubinski, and Benbow, 2009). As new systems and methods for doing things are developed to compliment smart campus initiatives, these systems will only be efficient and effective if they are designed with the cognitive abilities and limitations of the users in mind.

Additionally existing soft and hard infrastructures need to be retrofitted or adapted to meet the growing demands of modern campuses. Given this context (adapting infrastructure v. new infrastructure), how can we still achieve the goal of a spatially enabled smart campus? Is there a way to phase the development of a smart campus that is also “smart” in that functionality or productivity is not lost during any step of the process? Architects and designers are trained to

solve problems given a set of constraints. They deal with the issue of sustainability on a large scale. The role of the architect or designer in the spatially enabled smart campus is through the design of physical infrastructures, which humanize the technology. They create the interface through which people experience the smart campus physically and digitally.

Many stakeholders are clearly involved in advancing the spatially enabled smart campus—political leaders, urban planners, engineers, etc. Each brings different expertise and agendas to the conversation. As someone who is trained as an architect and a cognitive psychologist, I am no different. To realize the spatially enabled smart campus, a holistic approach is necessary, that considers both an integrative and an inclusive approach.

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Advancing the Spatially Enabled Smart Campus and Environmental Planning and Design

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Despite what seems like annual budget crises and ongoing fiscal stress on their systems we see universities, large and small, investing in their campuses, less as collections of classroom buildings but as extensive learning environments. The spaces and forms that combine to shape the daily spatial experiences of these students create a series of opportunities for spatial exploration and learning in an environment that is also generally information rich and well-enabled with information technology. As a designer, the linkage of these spatial experiences with technology and students excited about learning is an outstanding opportunity for exploring space as well as themselves.

Typologies of activities in a spatially enabled smart campus

While it will surely be an obsolete model by the end of the workshop, I offer this model as a starting point for considering some of the activities on smart campus. They are broken into living and learning. Within those further specific emerge:

1) Living

- a. **Active**—Students on larger campuses are increasingly relying on smart devices to navigate the daily challenges of life. While the classic example might be finding their way to classes on the first days of the semester, day-to-day living includes other uses. Students find themselves employing smart campus technologies for communication, monitoring their bus, finding a parking sense, tracking down friends or getting food.
- b. **Passive**—Active campus spaces might be enhanced by sensors that respond to student use of the space. In the evenings a central plaza might undergo multiple changes in lighting in response to fluctuations in the numbers or locations of students in the space. If students know that large crowds trigger a light show in a gathering place, it might incentivize socialization that is designed to be safer/friendlier/more academic. Maybe a group that completes laps around the library is rewarded with a video that is projected on the sidewalk.
- c. **Crowdsourced**—By contributing spatial data, students could help reshape their living environment. Every few years paths could be redirected based on voting on smart phones. Or campus designers could use data on shifting walking and biking patterns to alter locations for bike racks, paths, obstacles, or even course offerings.

2) Learning

Smart campus applications could support a variety of approaches to learning:

- a. **Spatial**—For our purposes spatial learning may seem the most obvious. Spatial learning games like ARIS could be integrated into the campus experience. New

students could be encouraged to explore a campus in a digital scavenger hunt. Basic spatial cognition and fairly advanced social studies could all be taught using tools like this. Since spatial literacy is enhanced by experiencing spaces, sequences, and

- b. Topical**—At larger diverse universities, there are a variety of topics that might benefit from topical uses of smart campus applications. Landscape architecture students might be guided around, plant to plant, in a digitally-led lesson in plant identification. Engineering students use iPads to find different support systems for pedestrian bridges or roof overhangs.
- c. Collaborative**—Technology is facilitating new ways of sharing creative and intellectual work. Students who use their tablet for drawing and sketching could post their drawing of the campus administration building in a digital map space where other sketchers could post their as well. This exchange is common in an analog art class, but crosses temporal dimensions with the technology. Further, if the sketches capture different parts of the central quad, they could be stitched together to create a collaborative 3-d sketched representation of the campus core.
- d. Casual Inquiry**—Curious students might find casual inquiry to be a great way to engage their surroundings. Who is Barker Hall named after? Just capture the QR code and get an answer on your smart phone. How do the wetlands on campus function? If you walk close to them, maybe your smart device will provide a link to more information?
- e. Direct Inquiry**—In some cases, student's devices could be active tools for research. As crowds move between larger spaces on campus, perhaps a tablet could be used to monitor the movement based on the university's own sensors spread through the spaces. Similarly, questions about weather or microclimate might be answered through live remote monitoring of sensors.

As the other position papers will inevitably show, this is not a complete list, but they may provide some useful boxes for an eventually taxonomy of smart campus activities, both real and imagined.

Using 3D GIS to Sustain our Campuses

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Buildings account for nine percent of US gross domestic product and almost half the country's greenhouse gas emissions and energy use. The impact of development over the last few decades is clear. With tools to forecast the impacts, the market and consumers would have been better informed regarding more sustainable alternatives.

The buildings industry is still biased toward a paper-driven model, or one with unstructured digital data having no real connection or spatial context to the world at large. One impact is the persistence of erroneous building data within authoritative systems for educational institutions and associated campuses. Another is the difficulty accessing and integrating it across multiple systems. This certainly is not helpful when efficient and instant access to accurate building information is required (National Institute of Science and Technology (NIST), 2004, pp. 3-1– 3-6). Our campuses and the buildings within them are inherently 3D, so the foundation for smarter buildings and campuses will not be based on paper, unstructured 2D systems, or even highly structured 3D technologies that are difficult to integrate with other systems. To understand and resolve the challenges facing those managing, working and living within campuses, systems providing greater context for individual building objects are critical.

Geographic Information Systems (GIS) is emerging in a new role within the industry for better communication, analysis, and interoperability. By restructuring Computer Aided Design (CAD) and Building Information Model (BIM) technology to take advantage of the inherent spatial relationships in a GIS, building information (BI) can be aggregated at all scales and integrated with other management systems throughout the building lifecycle. GIS can be exploited to provide key information for decision makers, so they can answer questions regarding the best manner to develop and manage campuses. It enables improvement of the urban form by providing the awareness needed to expose hidden patterns affecting performance, allowing those deficiencies to be corrected; thereby, ensuring its future viability. For example, using 2D, procedural, and Building Information Model (BIM) derived data to conduct urban growth modeling, zoning change visualization, and view quality/impact assessment. Forecasting the future is a fuzzy science, but one clear step we can take to reverse old and unfavorable trends is to realize that GIS can and should play a key role in managing and sustaining campuses.

GIS technology can be exploited to provide key facility information for decision makers when they need it. In this context it is used to answer questions regarding the best manner to develop and manage campuses. This ability is largely a result of the relational database technology underlying it, as well as the capacity for GIS to identify spatially related objects. Spatial relationships allow GIS to merge different worlds of knowledge—it is significant and powerful

because it unearths and exposes related patterns that would otherwise go undiscovered. It is a powerful system and enabling technology for shaping and managing campuses—one that:

- Provides a common and coordinated view, thereby increasing collaboration and understanding, while reducing risk and its associated costs.
- Enables visualization, analysis and comparison of possible alternatives to optimize performance, providing the analytical tools necessary for determining which strategy is the best short and long term solution.
- Can provide the support the building industry requires to realize more sustainable development practices and patterns.

The buildings industry is no doubt integral to the U.S. economy, having accounted for nearly nine percent of all US gross domestic product (GDP) during since 1980 (Pacific Northwest National Laboratory, 2010, 1.3.1, 1.3.2). It's also an industry where the output (buildings) accounts for almost half the country's greenhouse gas emissions and energy use (National Research Council (NRC), 2011, pp. S-2). With the benefit of hindsight these trends and the cumulative net impact of previous individual actions become clear. Had there been tools available to forecast the short- and long-term impacts of proposed development, the market, and consumers, would have been better informed regarding more sustainable alternatives. In this manner, it would have been possible for developers and architects to configure more efficient layouts to achieve the same net square feet (NSF) as other alternatives with more gross square feet (GSF) for the purpose of increasing profitability for developers and reducing energy costs for consumers.

It is clear today that enabling technology, such as GIS, provides industry managers and executives the tools required to be better stewards of the built environment. The common and coordinated awareness that GIS delivers provides a better understanding of the present. Shared awareness enables stakeholders to visualize and analyze data regarding the built environment, and its links to the world at large. This enables better collaboration among stakeholder disciplines; thereby, reducing the unknowns, leading to lower project contingencies, risk and cost.

By spatially organizing and linking the standards, policies and values that guide the development and ultimate form of the built environment to the analysis required to achieve shared awareness, GIS helps industry stakeholders to better understand the future. In this way, GIS provides stakeholders the predictive capability needed to manage and actualize performance of campuses. This ability allows decision makers to visualize performance and virtualize scenarios to improve the campuses they manage, thus ensuring its future viability. For example, it allows facility managers to abandon run-to-failure maintenance strategies, and instead adopt strategies for preventative and reliability centered maintenance, which can dramatically lengthen facility service lives, as well as reduce operating costs.

In conclusion, the past generation of ineffective communications and data interoperability has been a big resource drain for building owners and managers, as well as for the campuses where these buildings are located. Enabling smarter buildings and campuses requires us to correct these deficiencies. Forecasting the future is generally a fuzzy science, but one clear step

to reverse old and unfavorable trends is to realize that a more practical CAD and BIM technology, one with better GIS interoperability, can and should play a key role in managing and sustaining the built environment and the world.

As shown in the figures below, a GIS-based system for managing campus facilities can provide facility and real property stakeholders at a campus the awareness required to manage it, as well as the technology, tools and processes required to actualize its potential for optimal performance. GIS for the facilities and real property is powered by a Facilities Information Model (FIM), which serves as the primary data source for all managed facilities, throughout the entire Facility Management (FM) lifecycle. Information contained in the FIM can be visualized in geographic space via the GIS, thereby providing users of the system a common and coordinated view of the built environment. By further linking the FIM to authoritative data sources, stakeholder workflows, needed reports, and relevant standards, GIS provides industry stakeholders a predictive capability essential for understanding the future, as well as for optimizing it.

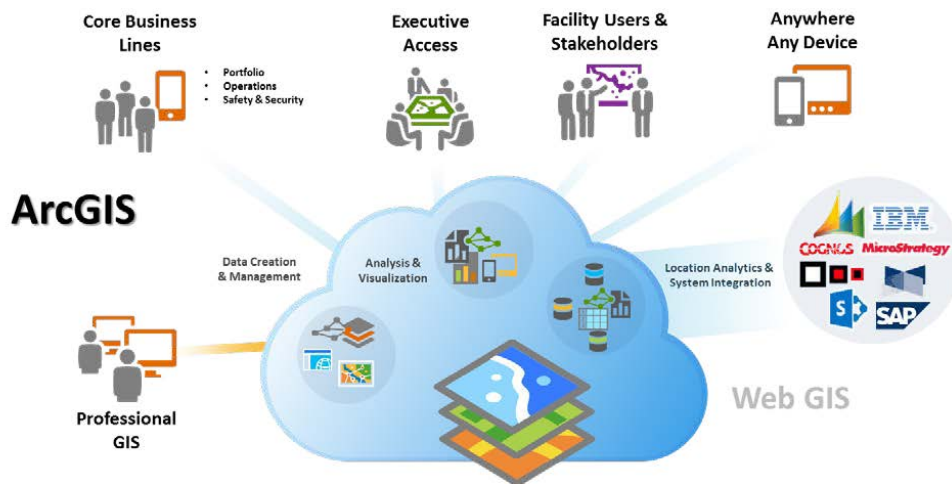


Figure 1: High Level Business Architecture

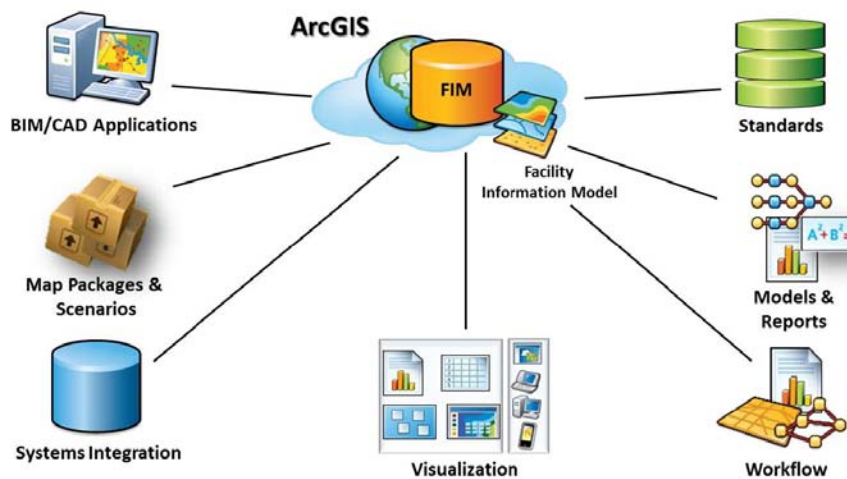


Figure 2: Conceptual Technical Architecture

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Creating a Spatially Enabled Smart Campus

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The opportunity to conceive, design and build a smart campus seems close at hand for some and still far away for others. For the technology providers who want to sell innovative solutions for sensing, social networking and knowledge integration, the smart campus (much like the smart city) is close at hand. For campus service providers responsible for real estate acquisition, facilities management, transportation and parking services, student housing, food and beverage services, class and classroom scheduling and public safety, among others, the design, creation and realization of a smart campus may seem a long way off in the future. Faculty and students with competing agendas may also participate and will often occupy some ill-defined middle space by promoting one-off solutions that are tied to specific workflows (i.e. writing code, implementing new proprietary or open source solutions) or interests (i.e. building new technologies, evaluating existing technology solutions such as new building performance, or conducting human subjects research). The realization of a smart campus will in all likelihood require all of these individuals but the fundamental challenge is to prepare and build support for a single, comprehensive vision and a series of nimble and evolving technologies and workflows that can be deployed to accomplish this vision and incorporate new solutions as they become available.

This single vision and the accompanying workflows that can incrementally move the campus toward the desired goal would require support at the highest levels and would be best organized around a series of campus services and their intended recipients:

- **Campus Services:** These might include the scheduling of classrooms, allocation of research space, provision and staffing of libraries and other specialized teaching and research facilities, provision of housing for faculty, staff, and students living on or near campus, provision of health care facilities and services, provision of recreation facilities and programs, provision of a range of dining opportunities for faculty, staff, students and a variety of campus visitors, the construction of new buildings and maintenance of existing buildings and related infrastructure, the provision of a safe and productive environment, and the provision of maps, signs and other artifacts to facilitate access to the various facilities and services that the university provides.
- **Campus Recipients (Participants):** The intended recipients will include the current faculty, staff, and students as well as prospective faculty and students, current and potential collaborators, vendors, service providers, alumni, and a range of visitors (i.e. family and friends at commencement, seminar and workshop participants, and fans attending sporting events, concerts, plays, and festivals).

That said, the most important observation might be that things can get complicated very quickly. Taking my own university, the University of Southern California as an example, we have two main campuses (University Park and Health Sciences) located approximately 8 miles from one another to the southwest and northeast of downtown, an expanding suite of satellite operations (in Culver City and Marina del Rey, on Santa Catalina Island and using various locations in and near Downtown Los Angeles), a rapidly expanding series of hospitals and health clinics spread across the Los Angeles Metropolitan Region, and a variety of university-sponsored, university-affiliated (i.e., fraternities and sororities) and private student housing options located near and far from the aforementioned campus facilities. In addition, the University will soon break ground on the largest mixed-use project (office, residential, and retail) in the City of Los Angeles in the past quarter century. The vision for the University of Southern California smart campus then would need to include all of these facilities and many of the surrounding neighborhoods because campuses seldom have crisp borders and there is a constant flow of people and materials linking the campus to the larger city and region.

The implementation plan, on the other hand, would need to focus on a series of specific deliverables and milestones and preferably a clear set of priorities so that we can make measurable progress over time. Some of these services would be provided by the appropriate campus units (the CAD Services group within the USC Facility Management Services Department for example) and others would be provided by outside firms, such as the contractors hired to construct new buildings and related infrastructure (heating, cooling, electricity, water, gas, landscaping, etc.). These activities will inevitably generate a variety of spatial products, such as survey-grade data delineating property ownership and easements and building information models. Some university-sponsored projects will also engage non-profits and these projects may yield spatial data as well – an example would be USC's recent partnership with the Advancement Project to characterize community assets and identify place-based research opportunities around the University Park campus. These activities and the accompanying spatial assets may afford new opportunities for research and teaching. For example, colleagues in the Viterbi School of Engineering have helped to build systems to: (1) track shuttles and report real-time results to customers with mobile phones; (2) improve the scanning and interpretation closed circuit video; and (3) model the performance of a series of recently constructed buildings using embedded sensor systems.

For our part, the faculty, staff, and students affiliated with the USC Spatial Sciences Institute have worked to build a series of collaborations that play to our strengths and advance our own vision of a spatially enabled smart campus. The following list describes the kinds of deliverables that will be provided:

- Installing and operating a community GPS base station at the Wrigley Marine Science Center on Catalina Island.

- Creating a series of map-based tours and story maps to document and promote both physical and virtual exploration of historically significant buildings and landmarks on the University Park campus.
- Creating a 3-D model of the University Park campus complete with photo-realistic outdoor and indoor facades and attributes depicting how interior and outdoor spaces are allocated and used, and then building a 3-D routing service and pushing it out to the Web and a variety of smart phone platforms.
- Creating a geocaching game to help new students explore the University Park campus prior to the first day of classes.
- Creating a series of customized tours for individual schools, departments, and other units and pushing these out to the Web and a variety of smart phone platforms.

The aforementioned examples barely scratch the surface and do little to illustrate how spatially enabled knowledge infrastructures and sensor networks, such as those connected with new buildings and closed circuit video systems, can be harnessed to promote spatially enabled smart campuses. There are many opportunities and most universities will lack the commitment and resources to pursue all of these opportunities simultaneously. This brings the discussion back full circle to the need for thought leadership and the articulation of a vision and accompanying priorities and workflows for building a state-of-the-art, spatially enabled smart campus over many years.

SPECIALIST MEETING

ADVANCING THE SPATIALLY ENABLED SMART CAMPUS

December 11–12, 2013
Upham Hotel, Santa Barbara, California

The Center for Spatial Studies at the University of California, Santa Barbara is organizing and hosting a specialist meeting about the smart campus. The meeting will bring together academic and industry representatives with interest in conceiving, designing, and building a smart campus. It will combine “thinking big” (asking what will make campuses smarter in the future) with “acting small” (focusing on specific organizational and technological measures and their evaluation).

Motivation

Making our daily environments smart through technologies has been on research and political agendas for more than three decades, with a primary interest in the outdoor environments of cities. Smart city projects are now found worldwide, focusing on sustainability, e-governance, transportation, health, etc. by deploying innovative technologies for sensing, social networking, and knowledge integration. To some extent, campuses can be seen as “small cities,” raising similar concerns for a particular kind of population. Additionally, smart campuses have their own challenges and opportunities, e.g., the support of creativity and interdisciplinary collaboration in science or the involvement of technologically savvy students. Spatial thinking and computing are thought to be key enablers for all these aspects of smart campuses, but this case needs to be made more effectively with university administrators and domain scientists.

Goals

This meeting will outline new frontiers for smart campus research and deployment. It will formulate scenarios of future campuses, define a prioritized list of services, and identify research needs to realize them. Experiences with smart cities and scenarios from that area will serve as inspiration and reality check. The unique challenges resulting from academic environments will be identified and related to the radical transformation of how universities enable learning, discovery, and invention. A particular focus will combine state-of-the-art smart campuses with spatially enabled knowledge infrastructures and sensor networks.

Means

About 30 experts and graduate students will convene to share and develop visions, insights, and best practices for future smart campuses. Plenary presentations and intense exchanges in small breakout discussion groups offer opportunities to develop:

- alternative and complementary scenarios for a “Smart Campus 2025”;
- research agendas in several areas (technology, institutional, and social aspects); and
- a repository of ongoing smart-campus projects, highlighting best practices.

Call for Applications

To apply, please submit a 2-page résumé and a 2-page position paper discussing your interest in smart campuses by **September 27, 2013**. Participants will be selected by the organizing committee and notified by **October 11**. Subject to approval, limited funding for travel and accommodation costs will be available to invited participants. Please go to <http://spatial.ucsb.edu/forms/asesc-applications/> for further details about this meeting and to submit an online application.

Participants will address such questions as:

- How can information-communication (ICT), volunteered geographic information (VGI), and sensor network technologies be deployed to meet smart campus objectives?
- How can geospatially enabled ICT/VGI contribute an understanding of campus diurnal/seasonal demographics and resource uses of buildings, pathways, and spaces?
- What are possible design features of a dashboard to best monitor and display smart campus implementations?
- How can spatially enabled smart campuses contribute to the learning, teaching, and research opportunities of students, staff, and faculty?

For more information and other questions of interest, see <http://www.spatial.ucsb.edu/events/ASESC/>

The meeting will achieve long-term impact by:

- publishing on research that enables smart campuses;
- exchanging best practices in a globalized Linked Universities network (<http://linkeduniversities.org/>) and
- formulating the case for space to university administrators, highlighting sustainability, knowledge sharing, student involvement, safety, and other perspectives.

ORGANIZERS:

Michael Gould (Esri)

Donald Janelle, Werner Kuhn, Mo Lovegreen

(Department of Geography, University of California, Santa Barbara)