Instrumentation of Buildings to Enhance Student Learning - A Case Study at Marquette University's Discovery Learning Compex

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INSTRUMENTATION OF BUILDINGS TO ENHANCE STUDENT LEARNING—
A CASE STUDY AT MARQUETTE UNIVERSITY'S DISCOVERY LEARNING COMPLEX

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ABSTRACT

INSTRUMENTATION OF BUILDINGS TO ENHANCE STUDENT LEARNING—
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The new engineering building at Marquette University, the Discovery Learning Complex, has been designed to change the way engineering education is delivered by using the building itself as a teaching tool for the next generation of engineers. The structural system for the building has been instrumented to allow students access to structural system data, wind speed data, and foundation pressures enabling this data from the building to be integrated into the teaching environment. The building also will display aspects of the building management system for public viewing. An array of weather stations will be installed on the roof, allowing the students to study wind turbulence, correlate wind speed to structural system response, and other educational pursuits related to alternative power generation opportunities in urban environments.

The concept of instrumenting a building for the purpose of education, rather than for safety or pure research, is relatively uncommon. With the use of Marquette University's new engineering building as a basis for knowledge and an educational tool, future design and construction teams challenged with a similar instrumentation project will gain insight and benefit from the data collected in this case study.

ACKNOWLEDGMENTS

I would like to thank the many people who have helped me in the preparation of this thesis; this endeavor would not have been possible without their support.

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Last, but not least, I would like to thank my mother. Her encouragement, love, and support have helped me immensely throughout my life and time at Marquette University. Thanks for reading and editing my thesis, I really appreciate your help.

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1.0: Introduction to the Discovery Learning Complex

The original vision statement for the new engineering facility at Marquette University, which was established in January 2006, was to "provide facilities that enable the transformation of engineering education and research into an experiential, collaborative discovery learning process, establishing Marquette University as having the premiere College of Engineering among Catholic Universities". The main guidelines used for conception and design were to create a world-class learning and research environment; provide a place where the students, faculty, alumni, and industry members can enjoy a sense of ownership and community; establish a new physical identity for the College of Engineering; increase the collaboration amongst students, faculty, alumni, and industry members; create outreach and service opportunities to the community; and to provide facilities that demonstrate and motivate sustainable design principles in engineering (Ganey, 2011).

At present, the new engineering facility, known as the Discovery Learning Complex (DLC), is in Phase I of construction. The Phase I site plan is displayed in Figures 1.0.1 and 1.0.2. Phase I is composed of a five-story, 115,000 square foot building which will be used as mostly laboratory and office space. The building is made of a composite steel structure, architectural brick precast wall panels that are gravity loaded to the foundation, and a curtain wall glass system (OPUS Development, 2010, p. 1). The lower level and level one are scheduled to be opened for use by the College of Engineering in August of 2011. Interior construction on floors two through five will continue after the lower level and level one floors open for use to obtain full occupancy in August of 2012 (Ganey, 2011).

Figure 1.0.1: Phase 1 Site Plan, Birds-Eye View

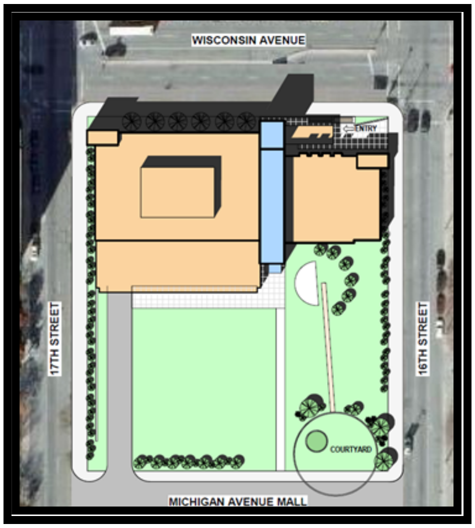

Figure 1.0.2: Phase 1 Site Plan, Close-Up

Marquette University and the construction team are pursuing a Leadership in Environmental and Energy Design (LEED) Silver certification. Some of the credits will be obtained through (OPUS Development, 2010, p. 3):

- Building on a brownfield site
- Utilizing a concrete parking lot to reduce the heat island affect,
- Recycling demolition debris from the structures previously on the building site and from construction wastes
- The use of low volatile organic compound (VOC) materials
- Specifying building materials with 10% recycled content
- Leaving exposed polished concrete floors
- Installing a 10,000 gallon rainwater collection tank which will collect the storm water from the roof to be used to irrigate the landscaping
- Installing low flow plumbing fixtures
- Selecting a heating, ventilation, and air conditioning (HVAC) system designed to perform 28% more efficiently than the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) code requirements
- Utilizing light-emitting diode (LED) lighting throughout the building as well as installing motion and light sensors to reduce energy usage
- Promoting and installing informational kiosk interactive displays tying into the living learning laboratory ideas

Photovoltaic (PV) panels are also being installed on the roof of the Engineering Material and Structural Testing (EMST) high-bay laboratory. These PV panels do not count towards LEED credits at this point because the amount of electricity they provide as a percentage of the building size is not large enough to qualify. Although the PV panels do not count for LEED credits it may be possible to obtain LEED innovation points from these devices; this possibility is being explored (M. Bratzke, personal interview, April 1, 2011).

The lower level has been designed to include various experiential laboratories including 1) an EMST high-bay teaching and research laboratory consisting of a strong floor and strong wall, 2) a materials testing laboratory, 3) a mixing laboratory for use by the Civil Engineering Department for mixing concrete, asphalt, and testing aggregates, 4) an engines laboratory, 5) an electric machine design laboratory, 6) a machines/drives/diagnostics laboratory, 7) a planned visualization laboratory, 8) a thermal fluids laboratory which will incorporate a wind tunnel and various mobile experiments, and 9) a thermodynamics laboratory with two canopy hoods and smoke exhaust systems to enable a variety of experiments (OPUS Development, 2010, pgs. 1-2). Level one will be comprised of a mix of laboratories, design spaces, and offices including 1) a systems integration laboratory, 2) a discovery learning electronics space, 3) multi-disciplinary design spaces, 4) a discovery learning shop, 5) a machine design area, 6) a large projects laboratory, 7) innovation laboratories featuring classroom space to introduce freshmen into the curriculum of the College of Engineering, 8) the Engineering Outreach offices, 9) student commons, and 10) a variety of seminar rooms (OPUS Development, 2010, pgs. 2-3). Floor plans of both the lower level and level one can be seen in Appendix C.

1.1: Objective of the Thesis

Instrumenting a building for the purpose of education rather than to ensure structural integrity and safety, or for pure research, is relatively uncommon in higher education. Marquette University's Discovery Learning Complex building project has been designed to include instrumentation specifically for the purpose of furthering the education of engineering students.

The focus of this thesis will be to add to the knowledge-base, helping future design and construction teams to improve the process of instrumenting an educational building through the lessons learned on this project.

1.2: Scope of the Thesis

This thesis presents the insights gained through the process of building Phase I of Marquette University's new engineering building. Chapter 2 contains a literature review consisting of current and common applications of building instrumentation as well as material regarding existing living learning center applications. Chapter 3 details the thought process behind the planning and installation of the DLC's instrumentation. This information was developed through interviews of key project team members. It covers the specialty sensors and instrumentation being installed in the project, the non-specialty sensors and instrumentation being installed, how the installation of the building's instrumentation was scheduled, how the cost of the installation was determined, how the installation of the instruments have or will affect the construction process, how the data collected will be displayed in the DLC, how the sensors and instruments will be maintained, lessons learned, and a comparison of possible project delivery methods. Chapter 4 concludes with several recommendations on how to improve the process and product for a future instrumentation project focused on enhancing student learning.

Chapter 2: Literature Review; Information Regarding Instrumented Buildings

2.0: Current/Common Applications of Building Instrumentation

During the programming stage of the DLC project, it was decided that the College of Engineering at Marquette University wanted the new building to be instrumented. Therefore, it was desirable to determine how other structures had been instrumented. After much investigation, a pattern emerged showing that the most common use for instrumentation in structures today is to monitor seismic activity.

2.0.1 To Monitor and Collect Data about Seismic Activity

Many buildings today are instrumented to determine the forces experienced during seismic activity in areas where earthquakes are prevalent. Instrumentation can be, and has been, installed in a variety of both small and large buildings in locations where seismic activity is common (Celebi et al, 2004, p. 1). If quality instruments are installed and well maintained, valuable and accurate data can be collected. This data can potentially be collected within milliseconds of seismic motion starting even after months or years of inactivity (Huang and Shakal, 2008, p. 60).

In recent years, the instrumentation used to measure the strong motion (Huang and Shakal, 2008, p. 60), specifically the shaking, twisting, and drift (Celebi et al, 2004, p. 2), that buildings experience during earthquakes, has become much more convenient, reliable, and accurate. Instrumented building systems today record data from the motion experienced in a building in a digital format which is relatively easy for computers to recover and process for use after an earthquake (Huang and Shakal, 2008, p. 60). The data collected by instrumenting a building for seismic motion measures the actual building's performance during an earthquake and helps to confirm the fundamental seismic design assumptions (Huang and Shakal, 2008, p. 61). The data collected from seismic monitoring can be used by engineers to create a better understanding of how buildings react to ground shaking, allowing both existing and new buildings in areas where seismic activity is prevalent to be strengthened to withstand projected motion of future earthquakes (Celebi et al, 2004, p. 1). This data can also be used to develop and improve seismic building codes. With these improved designs and codes engineers are better able to design structures for areas with seismic activity without drastically overdesigning their final product (Huang and Shakal, 2008, p. 61).

It has been determined that the sensor location is very important in recording the key information concerning a building's response to seismic activity. Certain building codes call for a minimum of a "tri-axial instrument to measure the acceleration in the vertical and two horizontal directions at the base, mid-height, and top of a building. These three locations, with a total of nine accelerometers, provide basic information about the motion of the building but are too limited to identify torsional motion or motion in most modes of the building" (Huang and Shakal, 2008, p. 60).

More extensive instrument layouts often place the tri-axial sensors in eight or more locations throughout a building. In some cases, buildings being used for the purpose of special research focusing on building movement place sensors in 50 or more locations. In all cases, the placement chosen for the sensors is determined by the locations that will obtain the most information possible regarding the global motion of the building" (Huang and Shakal, 2008, p. 60). It is also desirable in some geographical locations to place additional sensors in the ground beyond the instrumentation that has already been placed within the structure to measure the ground shaking and resultant effects on the building (Celebi et al, 2004, p. 1). In the best systems, all sensors are cabled to a central recorder where the data is recorded and kept together. To obtain quality data, it is important to ensure the devices recording the event have common triggering (Huang and Shakal, 2008, p. 60).

2.0.2 Instrumentation Analysis

Insight into instrumenting a building, even if not for the purpose of monitoring seismic data, can be gained using the information presented above. It is important to purchase high-quality and reliable instrumentation to ensure the data collected will be reliable and valid. Next, it is important to determine what is to be measured and place the sensors in appropriate locations to obtain the most usable information possible. Depending on the items chosen to be measured, an extensive instrumentation layout plan may be necessary. Lastly, designing for a central recording device that can capture and report all of the data and house the information in a single location will be extremely beneficial to the end-user.

2.1: Building Automation Systems

Marquette University currently uses a Johnson Controls building automation system called Metasys®[1] on campus. Metasys is used to control and monitor the mechanical equipment on campus, which includes equipment such as the air handling units and the central chilled water plant. If there is a failure, or if systems are operating outside of certain parameters, alarms are issued to the Department of Facilities Services to notify them of the problem (S. Wrenn, personal interview, March 1, 2011). This section describes what Metasys is capable of, as well as, reviews an alternative building automation system that performs essentially the same functions as Metasys.

2.1.1 The Johnson Controls 'Metasys' Building Automation System

Johnson Controls is a global diversified technology and industrial leader headquartered in Milwaukee, Wisconsin that focus on creating products to optimize energy and operational efficiencies of buildings (Johnson Controls, 2011c and 2011d). Metasys, a building automation and control system manufactured by Johnson Controls, is used to ensure that a variety of building automation systems in a structure (such as comfort controls, lighting, fire safety, and security) all integrate together into one, easy-to-use, automation system. This system was designed to be easy to configure and use with no special training by the end-user, and is customizable to the needs of each customer (Johnson Controls, 2011a).

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[1] Metasys® is a registered trademark of Johnson Controls, a technology firm with headquarters in Milwaukee, Wisconsin. More information about Johnson Controls can be found at: http://www.johnsoncontrols.com.

Metasys has an information-technology-based infrastructure with both software and wireless capabilities to provide information to the end-user in an intuitive and easy to access way (Johnson Controls, 2009a, p.8). By combining Metasys' Ready Access Portal (RAP) graphics and through customizing the set-up capabilities by the end-user, targeted views of data can be viewed in an easy to understand format (Johnson Controls, 2011a). Examples of three Metasys screen views from the Marquette University Law School building system can be seen in Figures 2.1.1, 2.1.2, and 2.1.3. These figures depict the layout and information gathered in an air handling unit, a condenser's water flow, and an evaporator's water flow respectively. Johnson Controls advertises Metasys as being designed for the way people work; whether they are at their desk or on the go, the end-user can utilize the latest web-based and wireless technologies to monitor and control a building system from wherever they may be. This allows customers to obtain the information they need to run their buildings efficiently whether or not they are in the office (Johnson Controls, 2009a, p. 2). The information from Metasys can be delivered to any personal computer, and is now also compatible with both the Apple iPhone and iPod Touch platforms (Johnson Controls, 2011a).

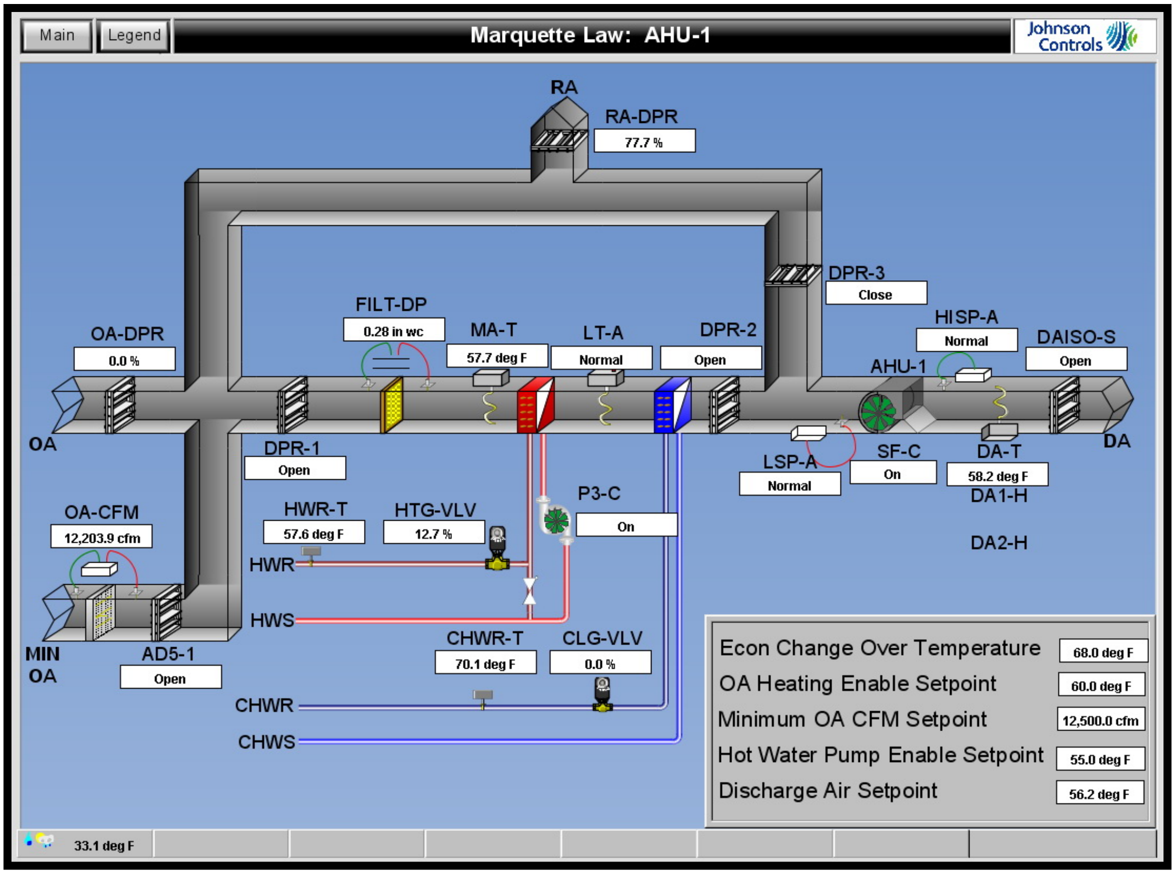


Figure 2.1.1: Metasys Screen View of an Air Handling Unit

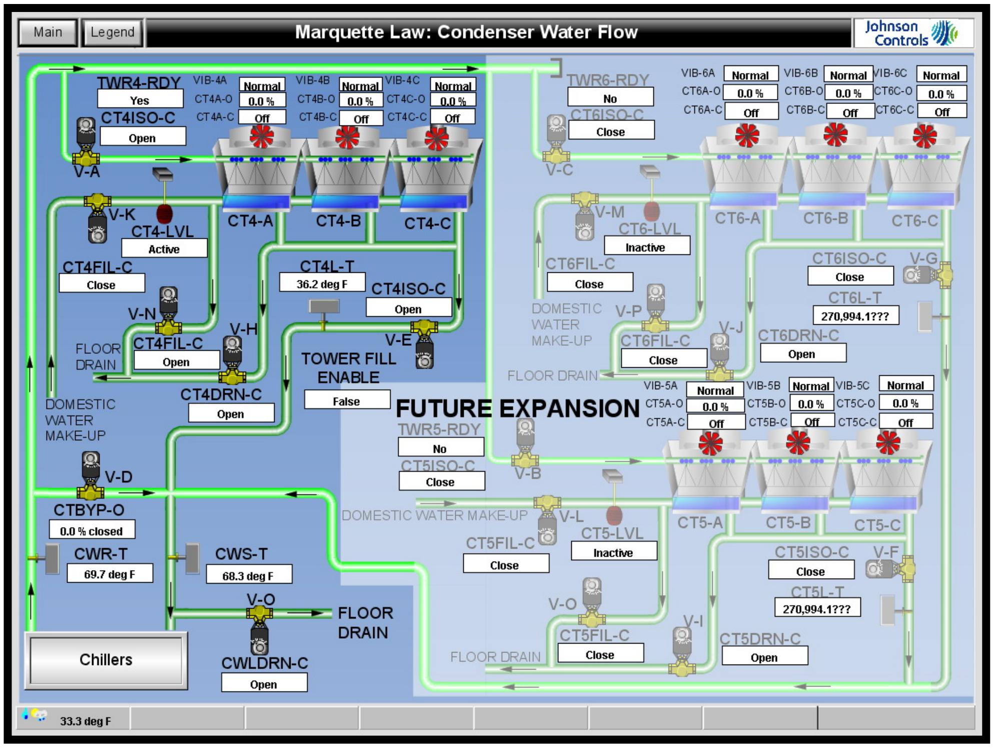


Figure 2.1.2: Metasys Screen View of Condenser Water Flow

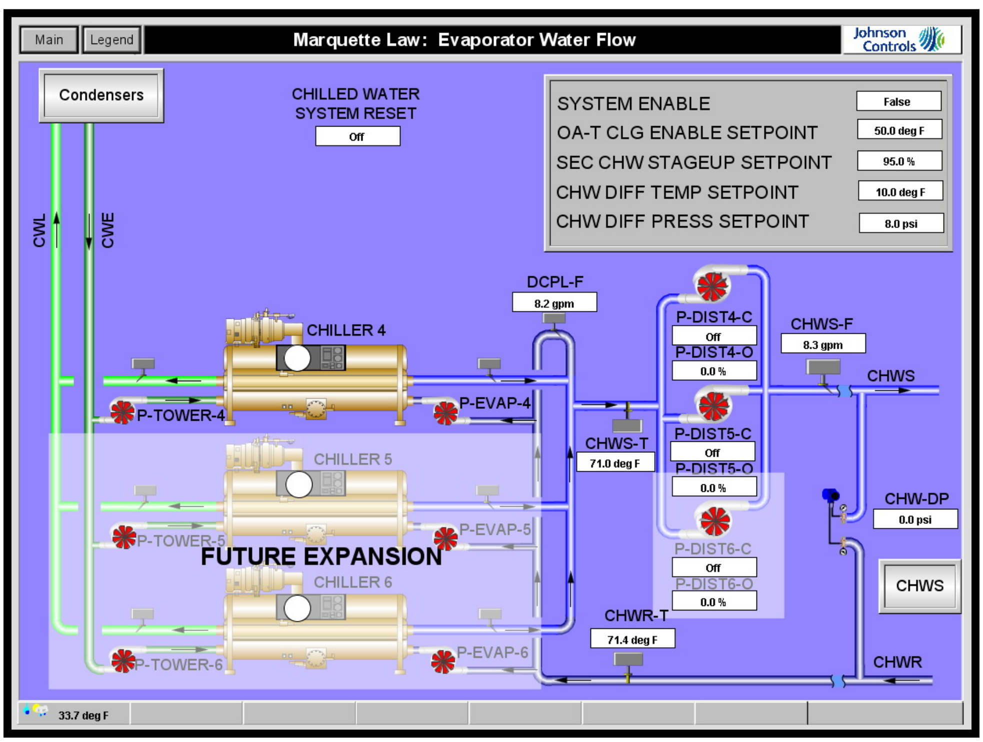


Figure 2.1.3: Metasys Screen View of Evaporator Water Flow

The goal of this system is to provide the end-user with more control and easier access to the information they desire by integrating all of a building's equipment information, organizing the data collected in a logical fashion, and delivering the information to the user where and when they need it (Johnson Controls, 2011b). This goal is achieved by having the ability to get thousands of different hardwired and wireless system devices and equipment to interface on a single platform (Johnson Controls, 2009a, p. 4). Supervisory controllers are used to facilitate communication and data transfer between the equipment devices using common IT standards to provide complete control and monitoring capability from any web-supported browser (Johnson Controls, 2009a, p. 6). With this technology, Metasys provides a flexible and reliable way to create comfortable, safe, and sustainable environments through its building automation process (Johnson Controls, 2009a, p. 8).

Energy efficiency is one of the main building factors typically monitored because many facility managers want to better understand and improve this aspect of their building system. Metasys allows the end-user to take real-time data and present it in an organized and informative way with easy-to-configure and easy-to-use energy reports (Johnson Controls, 2011a). Through the packaged equipment control, integrated central plant optimization, and system monitoring capabilities, customers are able to use the reports generated to act on critical locations within a facility to enhance overall building energy performance (Johnson Controls, 2009a, p. 6). Metasys allows the end-user to see up-to-date environmental impact, energy savings, and occupant information in their building(s) to help the customer make better decisions for their business (Johnson Controls, 2009a, p. 8). Using the tools provided through Metasys can not only make a building system more efficient, but can help a building to become more sustainable and reduce ownership and operating costs for the customer (Johnson Controls, 2009a, p. 6).

Another benefit of using the Johnson Controls' Metasys system is the service Johnson Controls provides to its customers to help maintain building performance. With offices throughout the country, local service professionals maintain and update each customer's Metasys system to ensure that each facility's performance specifications are being met. With the proper system maintenance, accurate control of temperature, lighting, and energy usage can be maintained to increase energy savings throughout a building's lifecycle. Customers can work directly with local Johnson Control representatives to develop a results-based service strategy and plan to meet any company-wide goals (Johnson Controls, 2009b, pgs. 1-2). Further insight on how Marquette University currently uses Metasys is discussed in "3.2: Non-Specialty Sensors/Instrumentation Selected and Their Purpose in the DLC."

2.1.2 The Honeywell Building Automation System

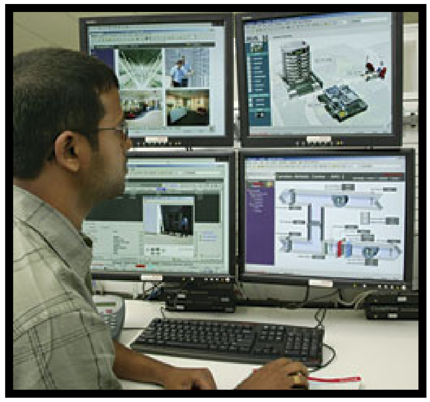
Based off of a suggestion from Erik Hendrickson from Marquette University's Information Technology Department (ITS), Honeywell was also researched to determine whether Honeywell offered a similar building automation system to the Metasys system. It was determined that Honeywell does provide a building automation system seemingly comparable to the Johnson Control's Metasys system.

Honeywell is a Fortune 100 company, headquartered in Minneapolis, Minnesota, that invents and produces technologies related to safety, security, and energy. Honeywell technologies are used worldwide, and their automation and control solutions are one of their four main business units (Honeywell International, Inc., 2011d and 2011e).

Honeywell building solutions are installed to integrate and maintain building systems that are used to keep structures safe, secure, comfortable, productive, and energy-efficient and tie all of the information into a single source (Honeywell International, Inc., 2011a). The building systems that can be monitored include: electrical, lighting, heating, cooling, security, fire, and life safety (Honeywell International, Inc., 2006, p.3). Honeywell provides an array of solution options, and tailors each project to its customer's needs. The building solution systems that can be provided include: management systems, HVAC temperature controls, energy services, and integrated security solutions. Honeywell can perform the installation, maintenance and support for the systems installed in any project, and also offers training for its customers (Honeywell International, Inc., 2011a).

A sub-set of the building solutions, building automation services provided by Honeywell are used to ensure optimum system performance through a flexible program that is customized to each user's needs (Honeywell International, Inc., 2011b). The control and automation systems can be implemented in new construction, expansion projects, or retrofits (Honeywell International, Inc., 2006, p.2) and is advertised to simplify the entire construction process beginning from system design, through installation, through commissioning, as well as through the entire lifecycle of the building (Honeywell International, Inc., 2011c). The building automation and control solutions provided have the ability to capture and store accurate data to improve a building's productivity, safety and security to help owners make better decisions and reduce the cost of owning and operating a structure (Honeywell International, Inc., 2011d). Examples of several Honeywell building automation system screen views are shown in Figures 2.1.4 and 2.1.5.

It is the goal of Honeywell to understand each customer's needs to respond with a system that is appropriate for their structure and to increase the reliability of the building's operations to reduce the operating costs for the customer (Honeywell International, Inc., 2006, p.2). Before Honeywell recommends a specific building automation system to its customer, an in-depth review of any current systems is done to provide a detailed list of services the system requires. The Honeywell building automation service also continues to analyze the systems installed and helps with application programming and software upgrades, component replacement, and staff support through the lifecycle of a building project. Once a system is installed, Honeywell will continue to monitor the system performance, schedule preventative maintenance when necessary, and identify and fix any problems a system may be having (Honeywell International, Inc., 2011b).



Figures 2.1.4: Example of a Honeywell Building Automation Screen View[2]

2.1.3 Comparison of the Johnson Controls and Honeywell Building Automation Systems

The Johnson Controls and Honeywell building automation systems are quite similar. Both companies provide their products and services worldwide in the technology market to optimize energy and operational performance within building structures. Each system integrates information from multiple building systems, such as lighting, heating, cooling, fire, and life safety, onto one platform for easy use by the customer. By using either system, the cost to own and operate a building can be reduced by improvements in the structures energy efficiency. Both companies advertise their product as being easy to use and customizable to the end-user's needs and desires. In addition, each company provides services to monitor, maintain, and update their systems throughout the life-cycle of the entire building.

[2] This image was found by Google Image Searching "Honeywell Building Solutions" and "Honeywell Building Automation Systems"; the direct website link is: http://www.facilitiesnet.com/buildingproducts/details/EBI-R400--3328?catID=143

Based on the information gathered from each company's website and informational pamphlets for the Johnson Controls and Honeywell building automation systems, it appears there are only limited differences between the two systems. Further consultation with the vendors, and work with the systems, would be needed to identify specific functional differences. Although each system can collect and store data, Johnson Controls advertises its use of real-time data whereas Honeywell does not specify whether real-time data is available to the end-user. It could be assumed that both companies provide this type of data based on how data is displayed and used by customers with both systems, but it was not directly specified by researching Honeywell's internet product material. Another difference was found in the easy-to-configure and use reports that Metasys can generate. The Honeywell system did not stipulate what kind of reports, if any, their building automation system can generate for their customer's use.

On the other hand, Honeywell describes an in-depth customer training program available upon installation of their product, whereas Johnson Controls does not mention a similar service. Honeywell also states that their control and automations systems can be installed in new construction projects, expansion projects, and retrofit projects. For expansion and retrofit projects, Honeywell provides a thorough review of the current systems that are in place within a structure before making recommendations to provide the best services possible to their customers. Johnson Controls does not specify what types of projects in which their building automation system can be installed, nor does it mention any services to evaluate existing building systems within a customer's project.

2.1.4 Further Analysis of Building Automation Systems

An advantage of implementing a building automation system within an instrumentation project is that the data collected can be integrated onto one platform, allowing the end-user to easily access the information from the mechanical, electrical, and plumbing systems being monitored.

Both building automation systems discussed above appear to be able to collect the data that would be interesting for use in an educational setting. Determining whether the professional services both companies advertise can meet the expectations of the customer is a challenge of implementing this type of system. Although Marquette University has built a working relationship with Johnson Controls through use of their Metasys system, the service provided has not always meet expectations. One way to manage this issue would be to speak with other customers who have implemented these systems and learn about their experiences with the company in order to determine whether or not the customer deemed the services provided as met their quality expectations.

Also, there needs to be someone inside the organization interested in using the data being collected by the system. Marquette University has had Metasys installed on campus for some time, but data relating to the environmental impact, energy savings, and occupant information has never been used. Those with access to the system have not been interested in using this information; rather, the system has been used to alert the Department of Facility Services of any equipment issues so the problem can be located and fixed. To make using a building automation system worthwhile for educational purposes, there needs to be internal commitment to use the system to its potential and designate a specific person, or group of people, to learn about and use the system analyzing data collected to enhance student learning.

2.2: Material Regarding Existing Living Learning Center(s) Applications

Incorporating living learning concepts in the new engineering building being constructed at Marquette University was established as a priority early in the design phases of the project. Members of Marquette University's design team viewed a building containing partially exposed and instrumented structural members at the University of Colorado at Boulder. The process of determining what components to include in Marquette University's new building is described in this section.

2.2.1 Marquette University's Initial Exploration into the Concept of "Discovery Learning" and the "Living Learning Center"

While it is common practice in university engineering programs to use instruments and sensors in their school's engineering laboratories; the extent of instrumentation issued varies by university. Although several universities have outstanding engineering facilities, the building structure itself is not commonly instrumented in a way that allows the collection of data that can be used as an educational tool.

In the early phases of Marquette University's new engineering building project, an Investigation Committee was established by the Dean of the College of Engineering to determine the best practices for constructing an undergraduate facility to support its curricula. This committee was comprised of two representatives from the design-builder and nine Marquette University employees including eight members of the engineering faculty along with the University Architect. The Investigation Committee was tasked with researching and visiting several engineering schools across the country to identify ideas of ways to best incorporate discovery learning concepts into the new curricula and facilities. The site visit reports and recommendations of the Investigation Committee were documented by the Committee Chair, Professor Richard Marklin. As discovery learning is a more hands-on, laboratory-intensive, and interdisciplinary concept, the team needed to investigate how other college facilities and programs provided for this type of learning.

The committee researched many colleges and universities and narrowed down the list of schools to ten primary schools to examine further and visit:

- University of Colorado at Boulder, Boulder, CO
- Massachusetts Institute of Technology, Cambridge, MA,
- Northwestern University, Evanston, IL
- Olin College, in Needham, MA
- University of Southern California, Los Angeles, CA
- Stanford University, Palo Alto, CA
- Villanova University, Philadelphia, PA
- University of Nebraska- Omaha, Omaha, NE
- Queen’s University- Kingston, Ontario, CANADA

- Lynne and Harry Bradley Technology and Trade School, Milwaukee, WI

The Investigation Committee members split into smaller groups to visit these schools and spoke with representatives at each school regarding their curricula and aspects that have been effective and aspects that have not worked in their programs. Upon their return from these visits, the committee made several recommendations for Marquette University's College of Engineering to consider that the committee believed would greatly enhance the effectiveness of the new building. All recommendations were based on the committee's recommendation of upgrading the engineering undergraduate curriculum while emphasizing discovery learning. The main recommendations summarized here were given regarding the design of the new building so that the design would reinforce a structure the committee believed would foster the new discovery learning focused curricula. A more detailed description of each recommendation is contained in the Investigation Committee's Site Visit Report and Recommendations written in September, 2005.

The first recommendation given to the College of Engineering for the DLC was the integration of spaces, furnishings, and equipment that would enable students to experience the full spectrum of the design process. This would encompass furniture that is easy to move around, design studios, and SMART Board[3] technology. The second recommendation was having modern equipment and infrastructure to enable students to physically make their designs full size in 3D and then subsequently test and operate them. A third recommendation was to have large windows allowing people outside of the facility the ability to see the students creating, building, and testing their designs which the committee believed could create interest in engineering as a

[3] SMART Boards are a copyright of SMART Technologies, website link: http://smarttech.com/

career for the observers. The fourth recommendation given by the committee was to have flexible spaces that would be able to be used for both instruction and laboratory purposes; creating a connection between practice and theory. A fifth recommendation stated the desire for the design and content of the DLC to convey good engineering decisions regarding stewardship of the natural environment because the committee believed that environmental consciousness is another necessary component of the revised curriculum. Additional recommendations included areas for studying, socializing, gathering, and food service; having multiple conference rooms of various sizes for use by the students, faculty, staff, and alumni; having a large lecture hall that could be used for both instruction as well as public speakers; having an exhibition area for traveling or permanent exhibitions of engineering science, technology, paragons of design, and/or winners of student design competitions; utilizing an efficient material handling system for loading and unloading materials and equipment; having ample storage spaces for material, equipment, and design projects; providing a space for student organizations; making facilities available for community outreach; and finally, a recommendation for a partially exposed and instrumented building.

This last additional recommendation, having a partially exposed and instrumented building, was something the committee observed at the University of Colorado at Boulder. The comments expressed their enthusiasm for the cut-away views of walls and beams monitored with sensors, exemplifying the use of this university’s facility as a learning tool for student understanding. An example of one of the cut-away views observed by the Investigation Committee at the University of Colorado at Boulder is displayed in Figure 2.1.1 (Investigation Committee, 2005, pgs. 27-28).

This particular recommendation is the focus of this thesis' study of Marquette University's new engineering building construction project.

Figures 2.2.1: Cut-Away Wall View from the Investigation Committee Report

2.2.2 How the University of Colorado at Boulder Uses Instrumentation, and What Marquette University Can Learn From Their Application of This Idea

The University of Colorado at Boulder's Integrated Teaching and Learning Laboratory (ITLL) is a 34,000 square-foot facility (University of Colorado, 2010a) that houses laboratories for all six of the university's engineering programs. The ITLL is a 3-story building that was built in 1997 at the cost of $17 million to complete (Investigation Committee, 2005, p. 26). This facility supports the university's Integrated Teaching and Learning Program (ITLP) which "supports hands-on engineering learning through an innovative environment where students integrate engineering theory with practice through doing." This program's goal is to foster creative and team-oriented problem-solving skills through a multidisciplinary learning environment. (University of Colorado, 2010a).

The ITLP was started by two professors in the College of Engineering at the University of Colorado at Boulder who wanted to improve the engineering curriculum to increase the undergraduate enrollments in the College of Engineering which had been declining since the mid-1980s. The design of the Colorado's ITLL, which was envisioned in 1992, was driven by the new ITLP approach of having hands-on and team-oriented learning as the core of the new curriculum (Investigation Committee, 2005, p. 27). The ITLL "was specifically designed to help students of all ages learn about engineering systems found in almost every modern building by studying the building itself - a concept they term Building-as-a-Learning-Tool, or BLT" (University of Colorado, 2010b). The concept behind using the building as a learning tool was to showcase how the building works, as well as how specific pieces function, leaving many parts exposed and visible to the public as well as being instrumented with a variety of sensors that collect data. This idea would leave very few secrets as to how a building works, enticing people to interact with the building and allowing students to use the data collected by the building in which they are studying in a theoretical manner in their coursework. (University of Colorado, 2010b). An example of an instrumented beam in the ITLL is displayed in Figure 2.2.2.

Figures 2.2.2: An Instrumented Beam in the ITLL, in the Hewlett Packard Lab Plaza[4]

The ITLL has a wide variety of sensors to measure many different values that are of interest to engineers. Specific sensor information and model numbers were not available, but the types of measurements being taken as well as where the sensors are located in the ITLL are (University of Colorado, n.d.):

- Temperature. This is measured at many locations including the thermal gradients through the walls, thermal performance of the window glazing, air stratification and operations of the air handling unit within variable air volume (VAV) units, and the atmospheric air temperature that is measured at the outside weather station

[4] This image was found on the University of Colorado at Boulder website link: http://blt.colorado.edu/ by selecting the "Several types of structural systems" option

- Flow. This is recorded through the flow of the air in the VAV unit and the air handling unit, as well as the water and steam flow in the air handing unit, heat exchanger and the cooling tower
- Pressure. There is a pressure control unit in the dampers of the air handling unit to maintain a predetermined air pressure in the building, as well as water and steam pressure measures in the water and steam circulation system (the heat exchanger) across the pumps
- Energy. The total energy usage of the centrifugal fans in the air handling unit, the pumps in the water and steam circulation system, and the condenser water pump in the cooling tower is measured
- Power. The sensors measure the power usage by the supply and return fan in the air handling unit
- Mass. The total mass of condensate pumped in the water and steam circulation system is measured
- Volume. The average, maximum, and minimum air volume is measured in the variable air volume unit
- Direction. Direction of the wind is measured on a roof-top weather station
- Speed. The speed of the wind is also measured at weather station
- Concentration. The concentration of dissolved solids in the fluid cooler sump water is measured in the cooling tower
- Insolation. The amount of solar radiation striking a surface, known as insolation, is measured at the earth’s surface when the sun is directory overhead

- There are also a variety of dimensionless measures such as switch status, relative humidity, and valve positions

2.2.3 Analysis of Exploring Living Learning Center Information

As Marquette University did before beginning the design of their DLC project, the next design and construction team challenged with a similar instrumentation project should explore other facilities in regards to their instrumentation efforts. By evaluating the items and decisions made at locations such as the University of Colorado at Boulder and Marquette University, and the decisions they made relative to what instruments to install and the data to be collected, the next team will have a good starting point for how to proceed with their instrumentation efforts.

Future projects will benefit through a better understanding of the potential problems that will be faced in their instrumentation effort, along with having the ability to avoid similar issues. Further, a deeper understanding of why specific items were instrumented, the types of information gathered, and how the information can be combined to increase student understanding of a building’s response will be dramatically enhanced.

Chapter 3: The Thought Process Behind the DLC's Instrumentation

To create a knowledge base that future design and construction teams can use to enhance prospective instrumented facilities, the thoughts and actions by those who developed and implemented the instrumentation of the DLC was required. A series of structured interviews were conducted, beginning in mid-November through mid-December of 2010, with a variety of important players on the DLC design and construction teams. Interviewees included: Marquette's University Architect, a Marquette University Project Manager who specializes in HVAC systems from the Office of the University Architect, the design-builder's Senior Project Manager, Project Manager, and Superintendent, the electrical contractor's Project Manager and Superintendent, the mechanical contractor's Project Manager, and two Marquette University engineering faculty directly involved in the instrumentation efforts. A secondary round of interviews was conducted in late February 2011-early March 2011 with construction team members involved with the technology aspects of the project. These interviews were conducted to augment information from prior interviews because very little, if any, information regarding the technology was available during the initial round of interviews. Interviewees included: Marquette University's Information Technology Services (ITS) Project Manager, Marquette University's College of Engineering Computer Systems Manager, and Project Manager of the design-build contractor for the building automation system/temperature controls.

Useful information and insight was gathered by conducting these interviews; the complete and raw data is provided in Appendix A. The following information distills the information collected from the structured interviews. It is important to note that during the interview period described the specialty sensors which had been installed included strain gauges on the structural steel and earth pressure cells placed in the soil. Three rooftop anemometers and rooftop weather stations were in the design stage with their locations selected. The actual products had not yet been selected during the interview period, nor had any modifications to the standard roofing installed begun to account for the rooftop weather station additions.

3.0: The Original Reasons behind Instrumenting the DLC

Originally, the Investigation Committee recommended having a partially exposed and instrumented building based on their research and observations while touring other universities. The actual instrumentation effort was completed through the collaboration of many faculty, staff, and design team members involved in the DLC project. Much time and energy was spent in the development of the instrumentation chosen and installed by the faculty members championing each specialty instrument. Several members of the design and construction teams discussed the decisions to instrument the DLC during the structured interviews. Two explanations are presented below.

The most simple and direct explanation given during the first round of interviews regarding the choice by Marquette University to instrument the DLC is that the College of Engineering is building a brand new building; why wouldn't you instrument it? Instrumenting the building and having partially exposed areas would be a great way to put engineering on display and hopefully get people interested in learning about engineering. Having interactive displays where anyone visiting the building can view a variety of building data to see what is happening within and to the building, is the essence of what discovery learning is (M. Jahner, personal interview, November 23, 2010).

Another reason given for why the building was instrumented was that for any class, in all engineering disciplines, using data from the building in the class that they are currently studying would be a valuable tool. The data collected would help apply theory and practice based on real-time information or previously collected data from the building instrumentation. It was estimated that overall approximately 75% of the information collected from the building instrumentation would be used for teaching and the other 25% used for research purposes (T. Ganey, personal interview, November 29, 2010).

An important consideration in the instrumentation effort of the project was to not over-instrument the DLC resulting in more data than what would actually be usable within the college. This goal was established based on what has been observed at the University of Colorado at Boulder where the instrumentation effort was done to such a great extent that now it appears no one is maintaining what was installed (T. Ganey, personal interview, November 29, 2010).

The specialty instruments chosen for implementation in Phase I of the DLC project were carefully thought-out, and Marquette University faculty and staff will have many opportunities to use the data collected from the different instruments to enhance the education of future generations of engineers.

3.1: Specialty Sensors/Instrumentation Selected and Their Purpose in the DLC

The specialty instrumentation selected to be installed in Phase I of the DLC project include earth pressure cells, strain gauges, and anemometers attached to rooftop weather station towers.

3.1.1 Earth Pressure Cells

Six Geokon earth pressure cells were selected and purchased to measure earth pressures. Two sensors are located under footings, one isolated (or regular) spread footing and one combined spread footing carrying two columns with a cross-brace, to measure foundation/contact pressures between a reinforced concrete footing and lean clay soil. Four sensors are located next to the soils pit in two pairs of two to measure at rest earth pressure in a granular soil. All earth pressure cell locations can be seen on the building foundation plan in Figure 3.1.1. The sensors next to the soils pit are placed in two sets of two sensors, with one cell in each pair measuring vertical soil pressures and one cell measuring horizontal pressures. The pairs are located at approximately mid-height and the bottom of the soils pit and will generally be measuring at-rest conditions (J. Crovetti, personal interview, November 23, 2010).

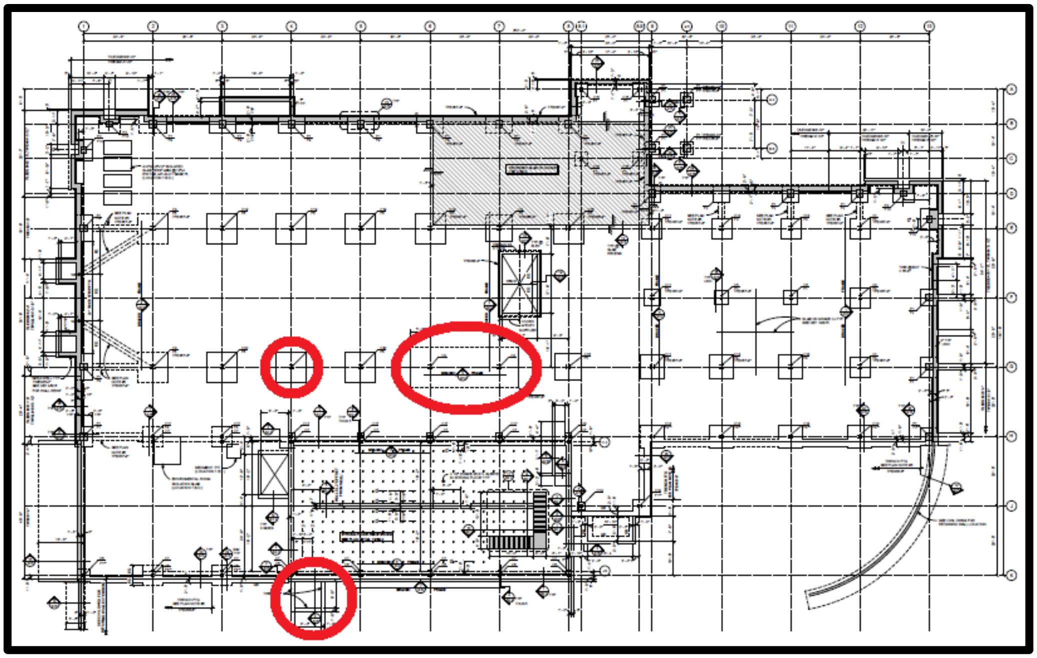


Figure 3.1.1: DLC Building Foundation Plan Showing Earth Pressure Cell Locations

The manufacturer of the earth pressure cells purchased, Geokon (2011), explains how this type of device works the best:

> "All cells consist of two circular stainless steel plates welded together around their periphery and spaced apart by a narrow cavity filled with de-aired oil. Changing earth pressure squeezes the two plates together causing a corresponding increase of fluid pressure inside the cell. A vibrating wire or semi-conductor pressure transducer converts this pressure into an electrical signal which is transmitted to the readout location."

The fluid pressure change being measured within the cell is representative of ground pressure changes which is of interest for applications in geotechnical engineering studied at Marquette University. Figures 3.1.2 and 3.1.3 show images of two different Geokon models purchased by Marquette University. The earth pressure cells purchased are able to measure dynamic pressure changes because it was desirable to be able to measure a transient load beneath the footings during a variety of weather events. Choosing pressure cells that are able to measure dynamic changes were chosen because of their ability to also read static loads. Had earth pressure cells been selected to only measure static pressure changes, the opportunity to measure possible dynamic loading situations would not be possible and therefore create a lost opportunity during a variety of weather events (J. Crovetti, personal interview, November 23, 2010).

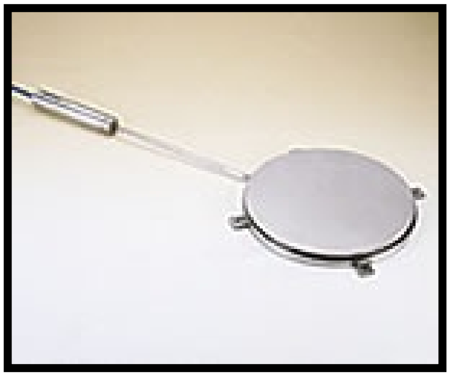


Figure 3.1.2: Image of a Geokon "Fat-Back" Earth Pressure Cell[5]

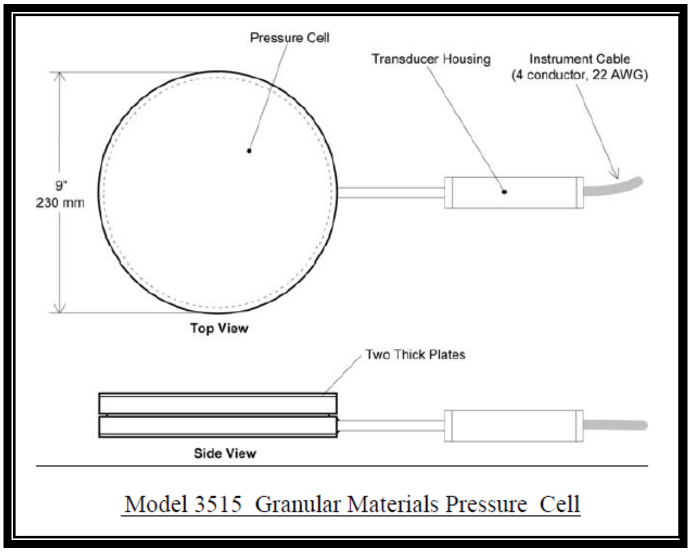


Figure 3.1.3: Geokon Model 3515 Earth Pressure Cell; Used by the Soils Pit[6]

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[5] Image found on: http://geokon.com/products/earthcells.php

[6] This image was found on: http://www.geokon.com/products/earthcells.php and selecting "Model (3500)"

As Dr. Crovetti had used similar types of Geokon earth pressure cell before, he knew they would work well for this application. Therefore, the cell options that were evaluated were: the type of plate (thickness/configuration), the type of sensor used for the plates, and the pressure range. The plate thickness/configuration of the pressure cell is dependent upon where the pressure cell is installed. There are three options for the plate configuration based on the thickness of the two plates in the system (which are described as thin-thin, thin-fat, or fat-fat) and two different types were chosen. The thin-fat plate combination (Geokon model 3510) was chosen to measure the pressures between the concrete and the soil beneath the footings, with the thicker plate embedded in the concrete and the thin plate on the soil (the standard installation procedure). The fat-fat combination (Geokon model number 3515) was chosen for the sensors next to the soils pit for a couple of reasons. Gravely soils have more localized contact pressures so a thicker plate is needed, and by having a fat-fat combination the potential for a biased reading due to contact forces from larger stones next to the device is spread out to obtain more accurate data. Another earth pressure cell option is the sensor. There are two options for the sensing device which include a vibrating wire or a semi-conductor pressure sensor. Dr. Crovetti selected the semi-conductor pressure sensor which allows for dynamic readings under live loading events as previously discussed. The last consideration which must be considered in the selection of the earth pressure cells is the pressure range. There are about fifteen different options to choose from, and in general it is undesirable to significantly overload or underload this type of device. Therefore, some time was taken to determine what pressure would be applied to each of these devices and the most appropriate range was chosen from what as calculated for each cell. Below are simple sample calculations completed to determine which devices should be selected. These calculations were provided by Dr. Crovetti who championed the earth pressure cell instrumentation:

<u>Sample calculation for the footing:</u>

- The allowable bearing pressures were listed as 10,000 psf = 69.4 psi
- The plans were reviewed and the maximum applied pressures appeared to be less than 60 psi
- The Model 3510-2-400KPA Earth Pressure Cell was selected, which has a range of 0-58 psi (0-400 kPa) with an overload capacity to 87 psi

<u>Sample calculation for the soils pit:</u>

- The bottom of the soils pit is 8 feet below grade
- Assuming a backfill material with a unit weight of approximately 130 pcf, the maximum applied vertical pressure would be approximately 1040 psf = 7.22 psi
- The Model 3515-2-100KPA Earth Pressure Cell was selected, which has a range of 0-14.5 psi (0-100kPa); this is the lowest range available in the “Fatback” version

After the earth pressure cells were delivered, pre-installation calibration tests were completed to simulate the actual field loadings anticipated on the earth pressure cells when placed beneath the DLC. This included extracting soil from the layer in which the earth pressure cells would be placed in the field for testing. The earth pressure cells placed were beneath the footings on soil that was gray, sandy-lean clay soil.   The calibration tests were completed to confirm linearity in the device readings and determine the true calibration factors for each device. This ensures an accurate load would be calculated from the logger reading once the sensors were placed in the field. Calibration factors are represented by the slopes of the linear equations used to determine the proportionality between the reading obtained from the logger device and the actual load experienced by the earth pressure cells. Although the manufacturer provides the calibration factors for their products, small variances between each device can create a slightly varied equation to be used when calculating the true load the device experiences. Figures 3.1.4, 3.1.5, and 3.1.6 show a portion of the progression of the pre-installation laboratory work developed and completed by Marquette University to obtain the proper calibration equations for each earth pressure cell. Figures 3.1.7 and 3.1.8 show graphs demonstrating how the earth pressure cells placed beneath the footings have slightly varied calibration equations. The calibration data collected in-house during laboratory testing to create these graphs can be seen in Appendix D.



Figures 3.1.4, 3.1.5, and 3.1.6: Calibration Process for Spread Footing Earth Pressure Cell

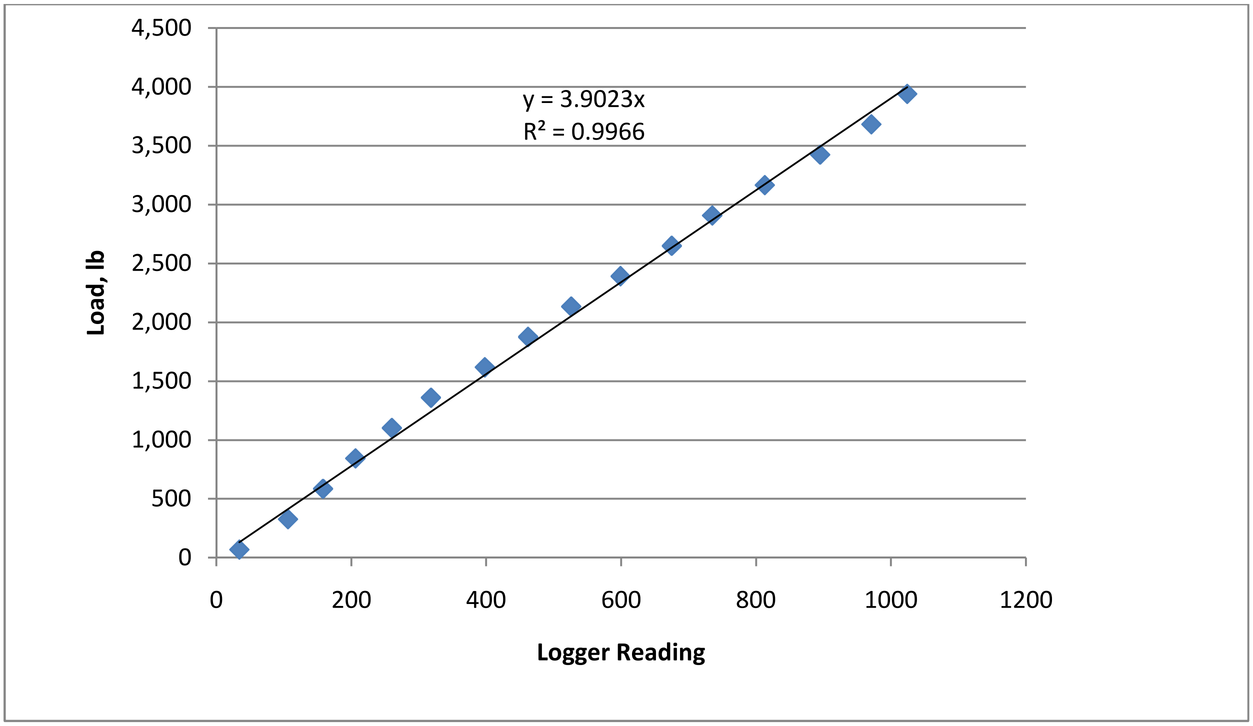


Figure 3.1.7: Calibration Factor for the Earth Pressure Cell, Regular Spread Footing

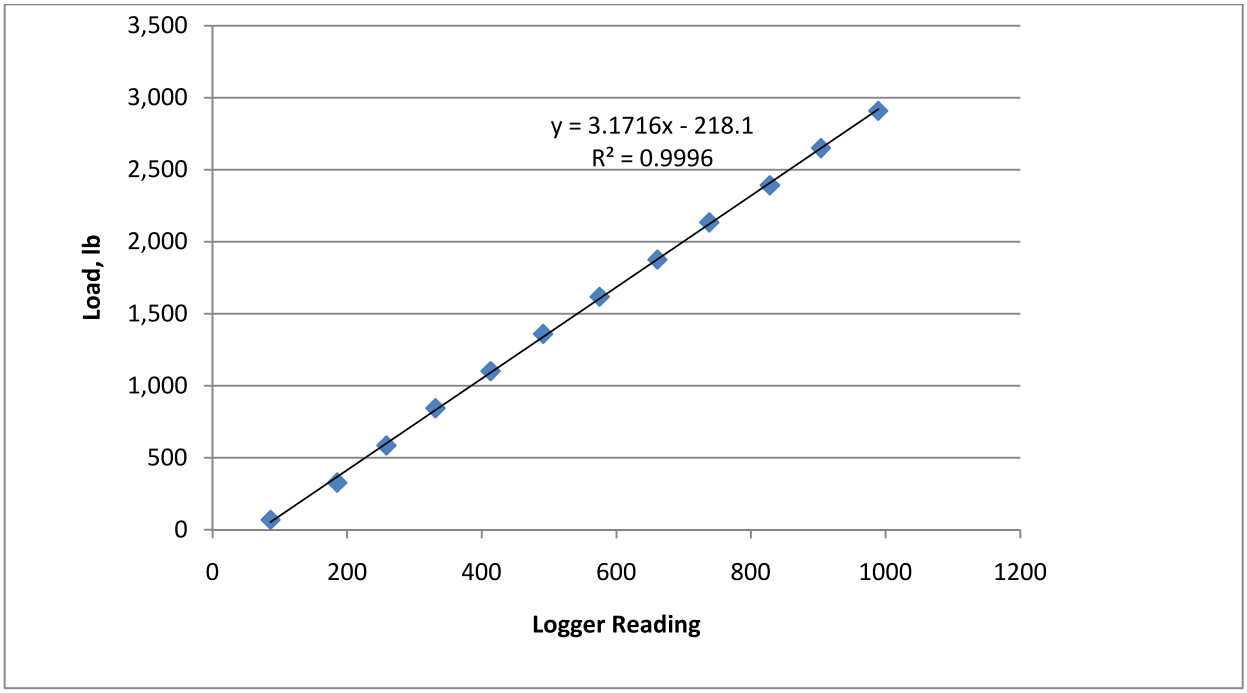


Figure 3.1.8 Calibration Factor for the Earth Pressure Cell, Combined Spread Footing

As Figures 3.1.7 and 3.1.8 show, the readings for both devices act in an almost perfectly linear fashion based on the R^2 value (R^2 equal to 1.0 is perfectly linear). These figures also show the variance in the calibration factors of the two devices. The earth pressure cell below the regular spread footing (G4) has an equation of Load = 3.9023 * Logger Reading whereas the earth pressure cell below the combined spread footing (G6) has an equation of Load = 3.1716 * Logger Reading - 218.1. Although the differences in calibration factors between the devices may seem small, establishing the actual equation through pre-installation calibration allows Marquette University faculty to obtain true load readings from each earth pressure cell.

The earth pressure cells installed beneath the footings have been collecting data as the rest of the building has been constructed. Figure 3.1.9 shows the plot of the data that has been collected through March 31, 2011. The line labeled “G4” represents the loading experienced by the earth pressure cell placed beneath the regular spread footing, and the line labeled “G6” representing the loading experiences by the earth pressure cell beneath the combined spread footing. The days on the x-axis of the graph are the dates and times of each reading taken converted to a numerical value for the ease of graphing, with a “day-one” date of May 1, 2010. For instance, the first point occurs at 24.63, which represents May 24, 2010 (23 days after May 1) at 3pm (63% of the day completed). One can use the loading information displayed in Figure 3.1.9 and tie it to significant events in the construction schedule to correlate how the soils were affected as the building was erected. In speaking with the Superintendent from the design-builder, the general dates for the three largest loading events occurred as follows: steel was erected from the beginning of June (approximately day 32 on the graph) through mid-July (approximately day 76 on the graph), the elevated concrete decks were poured from mid-July (approximately day 76 on the graph) through mid-August (approximately day 107 on the graph), and the precast concrete walls were installed from the end of August (approximately day 117 on the graph) through the beginning of October (approximately day 154 on the graph) (D.Nash, personal interview, April 14, 2011). As Figure 3.1.9 displays, there is a small increase in load from about day 30 through day 55, then a larger increase from about day 70 through day 90. These load increases graphically illustrate how the steel erection and concrete deck pours increased the foundation loadings. It is unlikely that the exterior wall placement increased the loads on the interior footings much, and therefore the more gradual increase in the overall foundation loads from about day 110 to day 150 is correlated to the ongoing interior work.

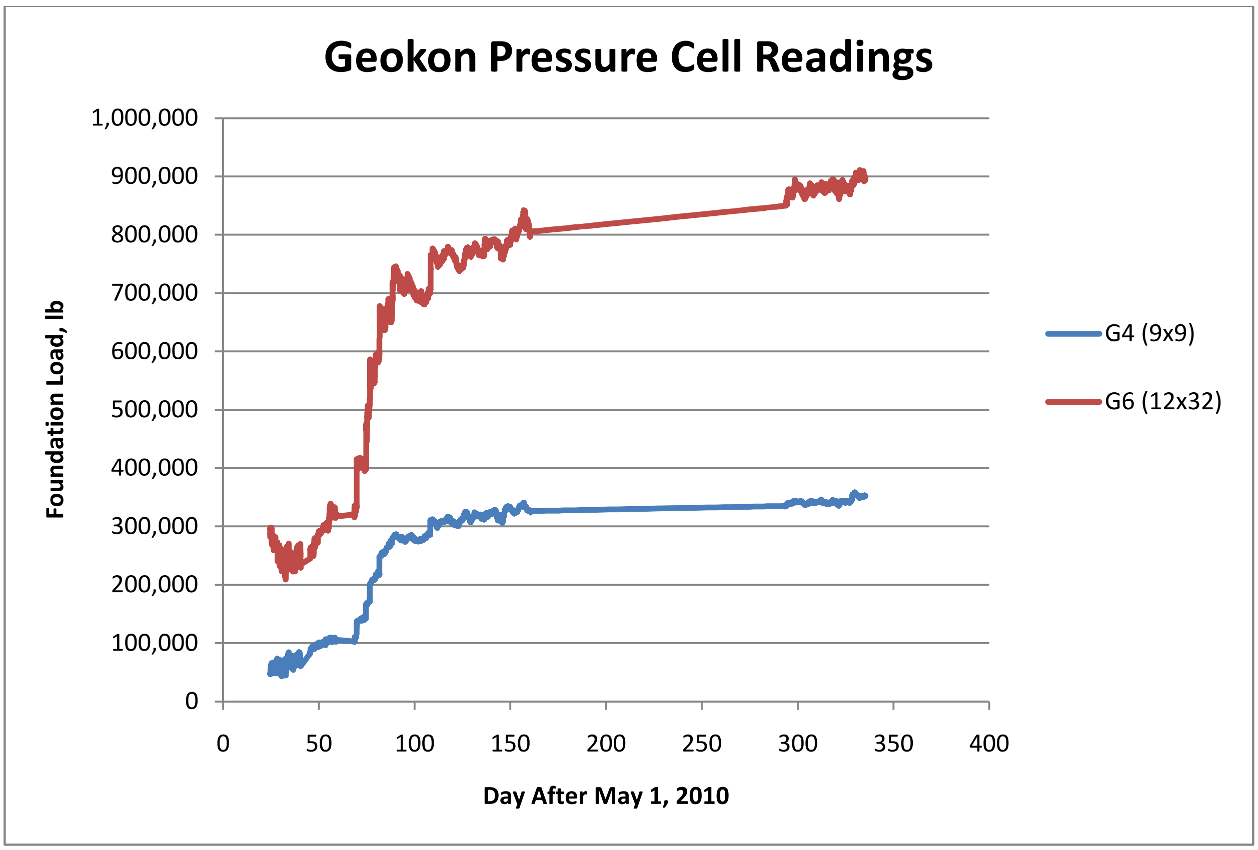


Figure 3.1.9: Data Collected From Spread Footing Earth Pressure Cells, May 2010-March 2011

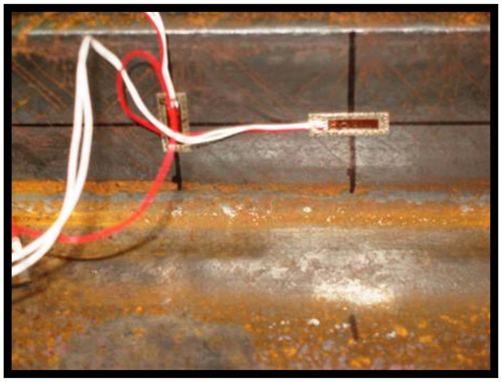
The data collected from the earth pressure cells are intended mainly for instructional purposes in the Geotechnical Engineering and Foundations Engineering courses. It is estimated that data readings will be done every fifteen minutes to an hour for the dead load applications as the data should be consistent and approximately flat-lined. The combined footing, where the dynamic readings are expected based on the structural cross-bracing present, will provide more dynamic data. During a particular meteorological event, such as a very windy day, readings may be collected more frequently. For instance, data could be collected at an increased rate of 10-cycles per second for a specified period of time to better understand the impact of these events. It is expected that this data will be beneficial to the College of Engineering's civil engineering program by increasing the understanding of the design implications of foundations on soils (J. Crovetti, personal interview, November 23, 2010).

3.1.2 Strain Gauges

Vishay[7] weldable strain gauges were selected to monitor strain in over 100 locations throughout the structural system in the DLC. The locations of these sensors were selected to maximize information related to the lateral load resisting response of the system, the gravity load resisting response of the system, and the load transfer mechanisms within the building. The sensor locations were also chosen with the thought of generating suitable data for use in civil engineering courses that incorporate structures and/or structural-mechanics. The strain gauge layout plan for the strain gauges can be seen in Appendix B (C. Foley, personal interview, December 8, 2010). Figures 3.1.10 shows a pair of strain gauges installed on a beam, Figure

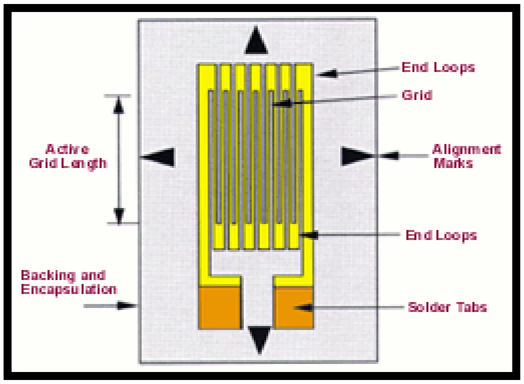
[7] Vishay is a sub-set of the Micro-Measurements Instrumentation Group; website: http://www.vishaypg.com/micro-measurements/

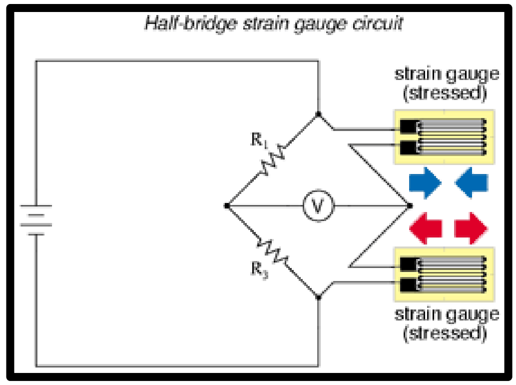
3.1.11 shows strain gauges installed on a diagonal brace frame, and Figure 3.1.12 shows strain gauges installed on a column that has been sprayed with fire-proofing material.



Figures 3.1.10, 3.1.11, 3.1.12: Installed Strain Gauges in the DLC

Strain gauges are available in a variety of shapes and sizes to meet a wide variety of strain applications. Generally this type of device is made of a resistive foil attached to a backing; when the foil is subjected to stress the resistance of the foil changes in a specified way signifying either a compressive or tensile strain. The strain gauge is then connected into a Wheatstone bridge circuit (Copidate Technical Publicity, n.d.). Figures 3.1.13 shows a standard strain gauge. The Wheatstone bridge, which is a direct current (DC) circuit, contains two arms that when strained produce a relative change in voltage. There are three common configurations of the Wheatstone bridge circuit: the quarter-bridge, the half-bridge, and the full-bridge (Schneeman, 2006, p. 76). Both the quarter-bridge and half-bridge configurations have been installed in the DLC, an example of a half-bridge layout can be seen in Figure 3.1.14 (C. Foley, personal interview, December 8, 2010). The least sensitive of these configurations is the quarter-bridge which utilizes a single strain gauge and three completion, or dummy, resistors. The half-bridge configuration contains two strain gauges and two completion resistors, having an entire arm with real strain gauges. The most sensitive arrangement, the full-bridge, uses four strain gauges and zero dummy resistors. Although the full-bridge arrangement is the most sensitive and has less error in its strain readings, it is also the most labor and cost intensive to install. In all configurations, when under strain, the actual strain gauge’s electrical resistance varies at a rate proportional to the magnitude of the strain to which it is being subjected while the dummy resistors (in the case of the quarter-bridge or half-bridge configurations) remain static. Generally, it is not possible to obtain resistors that have the exact same resistance leading to an initial state of imbalance across the Wheatstone bridge. This is due to the manufacturer’s inherent tolerances of the devices; these tolerances can affect the resistance of the gauges, the resistance of the dummy resistors, and potentially the lead wires attached to both the gauges and dummy resistors resistance. It is commonly required to calibrate each gauge and dummy resistor to verify the accuracy of the resistor network to determine whether there is an imbalance that needs to be corrected. This imbalance is normally corrected by mathematically subtracting the initial voltage differences found in the resistor network (Schneeman, 2006, pgs. 75-80). Most manufacturers of strain gauges also supply the accessories necessary for preparing, bonding, connecting, and cabling the devices for their application in the field. Some also offer bonding and calibration services either in their shop or on-site (Copidate Technical Publicity , n.d.).





Figures 3.1.13, 3.1.14: The Strain Gauge; Wheatstone Half-Bridge Configuration[8]

Although other sensor options exist, Vishay weldable strain gauges were selected based on their use in Dr. Foley's past research and teaching activity. He found these gauges to work very well in his past research, and also mentioned that virtually all health monitoring systems in infrastructure, health monitoring systems in buildings, and data acquisition (DAQ) systems in structural engineering research that involve steel structures use the same type of strain gauges as were chosen for the DLC which are mounted to the steel components within the building system.

The strain gauges were installed with the purpose of measuring both axial and bending strain. Depending on the sensor mounting surface and where the sensor is attached, the component will determine what each strain gauge is measuring. The rate at which data will be acquired is dependent upon the natural frequency of the vibration of the targeted modes in the structural system; for instance, the rate for lateral displacement may vary from the rate of vertical displacement. To simplify this idea, the goal is to acquire sampling data at a rate which is fast enough to capture the actual response of the building and to not have the data sampling create a false response. There will be many benefits of obtaining strain data from the DLC to Marquette

[8] Both images were found on: http://www.sensorland.com/HowPage002.html

University students as well as to civil and structural engineering students around the world. The data will be used to facilitate student understanding of what is done in engineering on a regular basis, namely, create models of physical behavior. These models then can be verified from the data obtained in the DLC. This data will help students learn how to develop and refine models to better predict the behavior seen through the DLC measurements.

Although sensors are becoming a common tool to collect data, Dr. Foley emphasized that for anyone instrumenting a building, it is a significant endeavor to establish the reasons for instrumentation as a whole, to select the appropriate type and location for these sensors, to determine reasonable and appropriate use of the data collected by students at Marquette University, and more broadly, in engineering applications and educational programs world-wide, and to decide how the data collected could be used in potential research. These levels of difficulty make instrumenting a building a significant intellectual challenge. Measuring the data is relatively easy, but understanding how to use the data (even if it is just in structural engineering) is more difficult. Dr. Foley believes that understanding how to use the data in engineering education is more difficult still, and assuring the data can be used to further the education throughout the nation (not just at Marquette University) is yet even more difficult. The process may seem easy on paper, but there truly is considerable difficulty in this process (C. Foley, personal interview, December 8, 2010).

3.1.3 Anemometers

An array of three weather stations including a wind anemometer, weather vane, and precipitation indicator, will be located on the roof of the DLC to help correlate the wind speed and direction as well as wind turbulence to the behavior measured within the building from the strain gauges (C. Foley, personal interview, December 8, 2010). It is anticipated that one of each of the instruments listed above will be placed in some fashion on a metal tower to create a weather station (E. Hendrickson, personal interview, February 25, 2011). Figure 3.1.15 shows an example of a weather station tower that is available for purchase from Campbell Scientific.

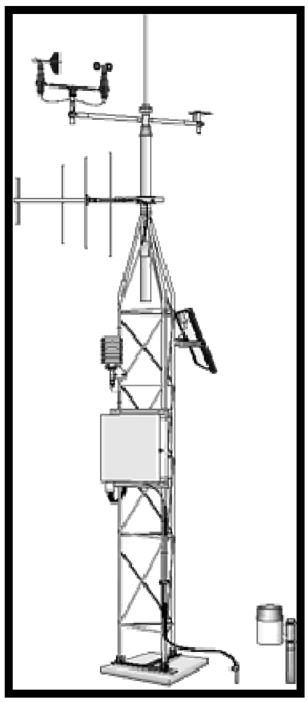
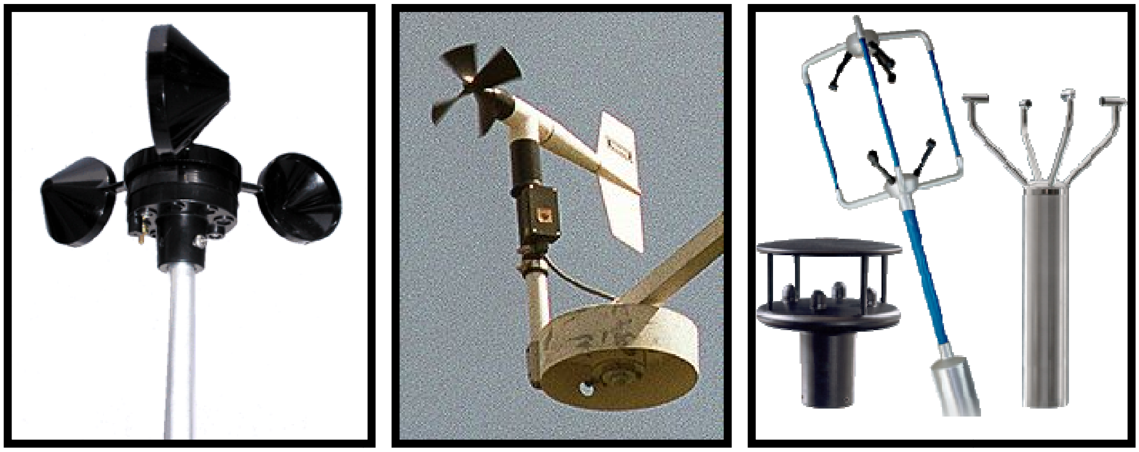


Figure 3.1.15: Example of a Weather Station Tower; Campbell Scientific Model UT10[9]

[9] This image was found on: https://www.campbellsci.com/ut10

An anemometer is an instrument which is used to measure wind speed (Oblack, 2011). There are three basic types of anemometers: the spinning cup anemometer, the windmill anemometer, and the sonic anemometer; an example of each of these basic anemometers is shown in Figures 3.1.16, 3.1.17, and 3.1.18 respectively. The spinning cup anemometer and the windmill anemometer are both simple instruments, while the sonic anemometer is more complex. The spinning cup anemometer usually has three or four cups mounted to a vertical pole (eHow, n.d.). The force of the wind causes the cups to rotate; the faster the wind speed, the faster the cups rotate (Oblack, 2011). The rotation of the cups is measured in revolutions per minute (RPM) and then converted from RPM to an appropriate wind speed unit such as miles per hour (MPH). The windmill anemometer also measures rotation in RPMs and then converts the rotations to an appropriate wind speed unit, but instead of having cups to catch the wind and spin the pole, this anemometer consists of a vertical pole with a horizontal shaft with a tailfin and a propeller mounted to it. The propeller is turned by the wind in the direction of the force to measure the wind's speed. Sonic anemometers usually consist of a pair of two ultrasound devices which face each other to send and receive sound waves between one another. These sonic devices are generally set about four to eight inches apart and measure how quickly, and in what direction, the wind travels between them. Sonic anemometers are also capable of capturing turbulence aspects in wind streams due to the available sampling rates inherent in these devices. These devices are much more complex than the other two typical types of anemometers, but are known to be able to take very accurate readings of the items they measure (eHow, n.d.).



Figures 3.1.16, 3.1.17, 3.1.18: 3-Cup Anemometer, Windmill Anemometer, Sonic Anemometers[10]

At the time of the initial interviews, the anemometers had not yet been selected, but the anemometers available from Campbell Scientific were being evaluated as it sells products from many vendors (C. Foley, personal interview, December 8, 2010). At the time of the second interviews the specific anemometers had still not been selected, but it was learned that the two types of anemometers being considered for installation at the DLC were sonic anemometers and three-cup anemometers, with a preference leaning toward sonic anemometers (E. Hendrickson, personal interview, February 25, 2011). By selecting to install sonic anemometers one of the goals of the anemometer installation would be met, which includes collecting data on the winds turbulence for student learning and research purposes.

The anemometers will measure the wind speed and direction as wind is the specific environmental condition that will be correlated to the internal response of the building as read by the strain gauges. The wind data acquisition rates will depend on which anemometer is chosen, but much like the strain gauge readings, the goal is to ensure that samples are being taken fast

[10] All images were found by Google Image Searching "anemometers"

enough to capture the actual response and to avoid creating false data by slow collection of the readings. What is different about the anemometers is that these readings are driven by the turbulent content of the wind, so the sampling will follow wind engineering principles to ensure the readings are being taken at appropriate intervals. The benefit to the College of Engineering is similar to the benefit mentioned in the strain gauge section, specifically, increasing student understanding by verifying models using data acquired from the DLC and learning how to build models based off of the attained data (C. Foley, personal interview, December 8, 2010).

3.1.4 Analysis of the Specialty Sensors Selected

Choosing to install these three types of specialty devices in the DLC was an intelligent combination of instruments. Through careful consideration, the data from the three types of specialty devices has the ability to be combined to display how a buildings structure and foundations react to outside forces such as wind, snow, and rain. By being able to tie the data collected from the earth pressure cells, strain gauges, and anemometers/rooftop weather stations together, the objective of using the building students are studying in as a living learning tool is fulfilled.

Even though the information from all of these devices can be tied together to represent the building's reaction as a whole, each device also has the capability of providing interesting display information. Being able to focus data from the foundations and soils through use of the earth pressure cells, a highly relevant tool for use in the Geotechnical Engineering and Foundations courses will be available. By having data on the buildings lateral load resisting responses, the gravity load resisting responses, and the load transfer mechanisms within the building from the strain gauges, students in Structural Engineering courses can better understand structural mechanics. By collecting data on wind and wind turbulences, an innovative and real-life experiential approach to enhance to current engineering curriculum is provided. All specialty sensors also will create several opportunities for focused research at the DLC.

Lastly, installing three types of specialty sensors in Phase I of the DLC generates wonderful opportunities to enhance the education process at Marquette University without over instrumenting the building. This avoids the issue of collecting so much data that it would be hard to incorporate the information into the undergraduate curriculum. Also, because this construction project is being completed in two phases, Marquette University has the opportunity to use the same sensors in Phase II of the project, or different sensors if other building and environmental features can or should be instrumented.

3.2: Non-Specialty Sensors/Instrumentation Selected and Their Purpose in the DLC

The sensors being called "non-specialty" sensors are those which are common to many building construction jobs. These types of instruments are typical building automation system sensors installed in many buildings at Marquette University (M. Jahner, personal interview, November 23, 2010). These sensors are essentially control instrumentation within the HVAC system and the mechanical, electrical and plumbing (MEP) system. These items are being managed by the mechanical contractor, installed by the electrical contractor, and monitored and controlled by the design-build contractor for the building automation system/temperature controls. There is a very large list of items that are being monitored, many dealing with water and air temperatures. A few examples include: water and air temperatures in the air handling systems, water temperatures in the heating system, water temperatures in the chilled water system, monitoring air flow at the air handling units and the variable air volume (VAV) boxes, and plumbing alarms (R. Kwiatkowski, personal interview, December 15, 2010). Thermal performance and energy usage are other items being monitored via the HVAC system. The location of all of these sensors directly corresponds to the HVAC system design and what items are desired to be measured (M. Jahner, personal interview, November 23, 2010).

The type of instruments selected for the non-specialty sensors are all Johnson Control devices and were chosen because they are consistent with other installations across campus. Although Marquette University is installing all of the same devices they have installed in other building applications around campus, the key for the DLC is the user interface that will accompany these sensors. Currently, the information these sensors record is used by the Department of Facility Services for maintenance, but in the DLC portions of the information recorded by these sensors will be available for viewing by anyone visiting or studying in the DLC (M. Jahner, personal interview, November 23, 2010).

Currently, all the non-specialty sensor data collected is recorded in the Metasys system which records real time information. Depending on how much data a person needs or wants, Metasys can record data every minute but usually the information is recorded in fifteen minute intervals. In the other buildings on campus these sensors and Metasys are used to locate an issue in the HVAC system so that the Department of Facilities Services can identify the location of the problem and deploy a technician to fix it. In the DLC however, these sensors will also be used to show the engineering students how the building performs from an energy consumption viewpoint (M. Jahner, personal interview, November 23, 2010). The type of information these sensors collect will allow the College of Engineering to evaluate the building as a whole, and make correlations to the building's energy usage and to the weather and temperature conditions outside. With the number and type of sensors in the HVAC and MEP systems, the vast array of data that can be collected will allow the College to develop a better understanding of the environmental impact of the building's energy consumption due to weather conditions. For example, in the summer the lawn of the DLC will need to be irrigated, and since there are fewer students around using water in the building, the College could determine how the water usage of the facility was impacted during this time of year (M. Bratzke, personal interview, December 7, 2010).

3.2.1 Analysis of the Non-Specialty Sensors Being Used

Marquette University's foresight in gathering information through the non-specialty sensors commonly installed within the building operational systems on campus will be rewarded by using this information to its full potential in the DLC. In addition, there is a wealth of pertinent and interesting information that can be correlated with the data collected from the specialty sensors. The information the non-specialty sensors collect related to the building's thermal performance and energy usage will be important to integrate into the Mechanical and Electrical Systems course in the Construction Engineering and Management program as well as into a variety of mechanical and electrical engineering courses.

3.3: Who Owns the Data Being Collected in the DLC?

The data that is collected from the instruments (the earth pressure cells, strain gauges, anemometers, and weather stations) installed in the DLC is owned by the College of Engineering at Marquette University (T. Ganey, personal interview, November 29, 2010), but could also be considered to be owned by Marquette University as a whole. This broader Marquette University ownership could be asserted in that all members of the Marquette University community will have the ability to see and track the data being monitored through the displays that will be installed in the DLC. Therefore, anyone who has access to the monitoring devices for this data would be able to use the information generated as long as the data is accredited to being collected at Marquette University. (M. Jahner, personal interview, November 23, 2010).

Although the College of Engineering and Marquette University would own the data collected in the DLC, certainly the intent is for this data to serve educational purposes for both Marquette University and universities worldwide. As long as the data collected remains the intellectual property of Marquette University, its use to further the education of engineering students across the globe is acceptable and encouraged.

3.4: How the Installation of the Sensors/Instruments Were Scheduled

The installation of the specialty instrumentation was not a separate activity in the design-builder’s general construction schedule; rather, these items were incorporated into the schedule previously developed for the project. The construction team members who were the most knowledgeable on how the specialty sensors were incorporated into the construction schedule were the design-builder's Senior Project Manager, the electrical contractor's Project Manager, the design-builder's Superintendent, and the electrical contractor's Superintendent. As the non-specialty sensors had not yet been installed in the DLC at the time of the interviews, and are a fairly standard part of any building project, insight as to how these items will be scheduled was given mainly by the Project Manager from the mechanical contractor. Further information regarding how the installation of the specialty instruments was scheduled was conveyed in the structured interview answers which can be found in Appendix A.

3.4.1 Earth Pressure Cells

As Dr. Crovetti had determined the specific type and amount of earth pressure cells that would be a desirable addition to the instrumentation of the DLC by the time excavation had begun, these items were very easy to schedule into the project. Essentially, the earth pressure cells were a minor add-on to the main schedule. After selecting the exact earth pressure cells for purchase, Dr. Crovetti purchased these items and was later reimbursed by the Department of Civil and Environmental Engineering at Marquette University.

The design-builder's Senior Project Manager, Matt Bratzke, commented that the construction team worked with Dr. Crovetti as to where he wanted each of the sensors to be placed on the project. The construction team continued to communicate with Dr. Crovetti about when each area an earth pressure cell was to be placed would be under construction and had him come to the site to install the sensors. For the earth pressure cells placed beneath footings, Dr. Crovetti was on site to ensure the placement of the sensor was correct, and then concrete was placed on top of the sensor. For the earth pressure cells near the soils pit, Dr. Crovetti was on site during the backfill of that area (M. Bratzke, personal interview, December 7, 2010).

3.4.2 Strain Gauges

The strain gauge installation was also a fairly easy addition to the general construction schedule because the work to determine the number and placement of the sensors for the DLC had been completed by the time the main steel structure was erected and before the fireproofing had begun. Had the strain gauges been selected later in the project both the installation and activity scheduling would have been a significant challenge. When determining how to schedule the strain gauge installation, the main goal of the installation was to attach the sensors to the structural beams prior to the fireproofing activity since then the sensors could simply be sprayed over with fireproofing, assuming the wires connecting to the gauges remained exposed (M. Bratzke, personal interview, December 7, 2010). Ensuring that the sensor installation was completed in the correct sequence of the building construction was another aspect evaluated during the scheduling of this activity (D. Nash, personal interview, November 29, 2010).

Had the strain gauges been selected or installed later in the project the fireproofing would have had to be cut away where the sensors needed to be placed, the steel cleaned of any residual fireproofing, each sensor welded to the steel, and then each of these areas would have been hand-patched with fireproofing applied to the steel. Although this could be done, the hand-patched fireproofing would not match the rest of the sprayed on fireproofing which would be undesirable as much of the structure is exposed and the hand-patched fireproofing would stand-out and look bad next to areas with sprayed on fireproofing. Luckily, the Marquette University team had planned ahead sufficiently to avoid this issue. (M. Bratzke, personal interview, December 7, 2010).

As the installer of the strain gauges, the electrical contractor's scheduling was a coordinated effort with the university/professor as well as with the design-builder. The electrical contractor kept in contact with the professor as to when the expected delivery dates were for the product so they could anticipate when the sensors would arrive on site. The electrical contractor also had to coordinate their installation effort with the design-builder to understand where the window of time was to ensure the sensors were installed prior to the fireproofing and also make sure they could fit their install into the design-builders's construction schedule and align their installation sequence with the construction sequence (M. Lochman, November 30, 2010).

3.4.3 Anemometers

At the time the interviews were conducted this specialty-sensor item had not yet been scheduled. In speaking with the Senior Project Manager from the design-builder, the goal here would have been to install the weather stations prior to the standard roofing installation, but the construction team did not know the full extent of the weather towers and anemometer installation prior to the roof installation. The installation of these items will be somewhat more difficult now that the roofing is in place. The roofer will now have to return to the site, and install more flashing (a roofing component which is overlapping to ensure water tightness) and then re-flash (re-doing areas that had already been flashed) those areas around the three towers. (M. Bratzke, personal interview, December 7, 2010).

3.4.4 Non-Specialty Sensors

Unlike the specialty sensors, the scheduling the installation of the non-specialty sensors followed the construction sequence for the project, which was driven by the design-builder's construction schedule as these items were a standard activity within the HVAC and MEP installation. The mechanical contractor indicated that the process of scheduling the non-specialty sensors is essentially a combination of design-builder requirements and the delivery of the equipment. For example, when the roof top unit arrives on the site, the mechanical contractor can then call the design-build contractor for the building automation system/temperature controls to tell them the unit has arrived and that they can start the installation and wiring of necessary sensors on the unit (R. Kwiatkowski, personal interview, December 15, 2010).

3.4.5 Analysis of Instrumentation Scheduling

None of the specialty instrumentation in the DLC project was scheduled into the design-builder's general construction schedule; rather, all items were placed into the windows of opportunity presented within the previously established project schedule. Having each type of sensor as an activity in the construction schedule would greatly benefit the next team managing a similar instrumentation project. By establishing each specialty sensor as an activity, or series of activities, team members managing the selection, ordering, and placement of each sensor or instrument would have better established timelines and goals for the instrumentation effort. By scheduling each instrument, any confusion about when items must be installed would be alleviated through communicating the dates and amount of time allotted in the schedule for the installation of all sensors. This also can help team members schedule any specialty training necessary prior to the installation, ensuring all items will be installed properly.

It is quite likely that scheduling specialty instrumentation in the general construction schedule is an increased challenge when using the design-build delivery method. Making sure the project team understands the impact of the project delivery method on their ability to manage an instrumented project is an important consideration. This notion will be further analyzed in section “3.10: Project Delivery Method Comparison” of this document.

3.5: How the Cost of Installation Was Determined

The cost of the installation of the instrumentation was best known by the following construction team members: the electrical contractor’s Project Manager, the design-builder’s Senior Project Manager, and the mechanical contractor’s Project Manager.

3.5.1 Earth Pressure Cells

There were no additional costs associated with the installation of the earth pressure cells. Through good communication between the construction team and Dr. Crovetti the window of opportunity to place the devices beneath the footings or next to the soils pit was established and the devices were placed without affecting the construction schedule (M. Bratzke, personal interview, February 8, 2011).

3.5.2 Strain Gauges

The cost of the strain gauge installation was a part of the design-builder's subcontractor allowance with the electrical contractor. This labor cost included the budget amount of what the electrical contractor believed it would cost to install the 120+ strain gauges. The material costs of the strain gauges were funded separately from the construction costs by the Department of Civil and Environmental Engineering. (M. Bratzke, personal interview, December 7, 2010). The electrical contractor's budgeted cost for the strain gauges was determined in a few steps. First, the Project Manager and the Superintendent from the electrical contractor read through the installation instructions provided to them for installing the strain gauges. Then they collaborated to estimate how long they believed it would take to attach each sensor to the column. The next portion of their estimate was to determine the cost of cabling. They decided to look at the cabling of the strain gauges as if they were a data drop because both applications use low-voltage, plenum rated cable. From what they determined, a simple estimate was built based off of the number of sensors and the average length of cable being run from the sensor to the data closet. Using this information, the average cable distance was multiplied by the quantity of sensors to determine the amount a cable and therefore determine the total material cost for the budget. The Superintendent and Project Manager also determined what they thought would be the average time to install each sensor and multiplied that amount by the number of sensors to establish the total number of hours it would take to install each item. As the electrical contractor's sub-contract with the design-builder already establishes an hourly rate and fee that can be billed, it was easy to determine this cost after figuring out the total number of hours needed for the installation. Therefore, the total material cost and the total number of hours to install the sensors were the basis for the electrical contractor's budget for the strain gauge installation (M. Lochman, personal interview, November 30, 2010).

3.5.3 Anemometers

As the anemometers had not yet been selected at the time of the either the original set or second set of interviews, the cost of installing these items was not available. One issue that needs to be resolved before these costs can be determined is to determine who is best to install this type of item. This will involve determining which trade union claims jurisdiction over this type of work. Again, had information on these items been available and decisions made sooner regarding the anemometers, some costs could have been avoided and money saved because now the roofer will need to return to site and complete additional flashing work once the anemometers are installed. This roofing work was previously discussed in the "3.4.3: How the Installation of the Sensors/Instruments Were Scheduled, Anemometers" section of this document (M. Bratzke, personal interview, December 7, 2010).

3.5.4 Non-Specialty Sensors

The cost of the non-specialty sensor installation on this project was prepared differently than it usually is done for standard projects and other Marquette projects involving this type of instrumentation. Usually the mechanical contractor would place the bid for these items, carry the cost of installation, and monitor the costs being incurred. On the DLC project however, the design-build contractor for the building automation system/temperature controls and the electrical contractor prepared the temperature control system proposal as a direct bid with Marquette University. Otherwise for the rest of the mechanical system, the design-build contractor for the building automation system/temperature controls is a sub-contractor to the mechanical contractor and the electrical contractor is a sub-contractor to the design-build contractor for the building automation system/temperature controls. (R. Kwiatkowski, personal interview, December 15, 2010).

3.5.5 Analysis of Determining Installation Costs

The only items that had established installation cost estimates at the time of the structured interviews were the strain gauges and non-specialty sensors. Evaluating the costs associated with each specialty item after the completion of Phase I of the DLC project to determine the actual labor costs associated with the installation of each device and what those costs were would be a valuable addition to the knowledge base of instrumenting a building. By evaluating the costs associated with each item installed in Phase I, the estimated costs for similar items in Phase II will be more accurate and easier to determine.

3.6: How These Instruments Have or Will Affect the Construction, Special Training and Difficulties in Instrument Installation

Many construction team members were able to comment on the impact that the specialty and non-specialty instruments have, or will have, on the construction of the DLC. These team members include the Senior Project Manager, Project Manager and Superintendent from the design-builder, the electrical contractor's Superintendent, and the mechanical contractor's Project Manager.

3.6.1 Earth Pressure Cells

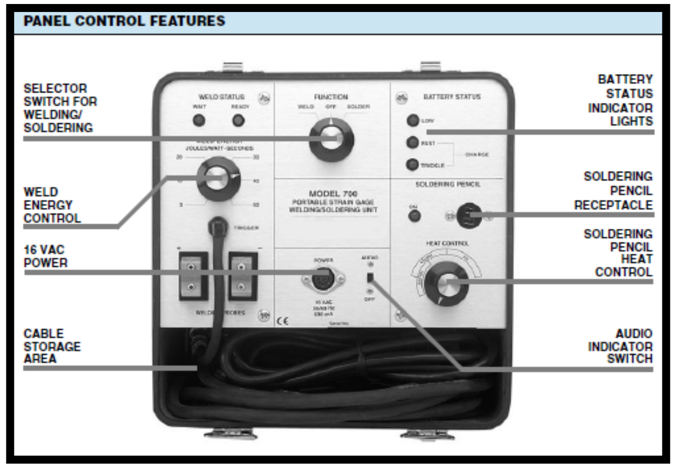
As previously discussed, installation of the earth pressure cells occurred through communications between the design-builder's construction personnel and Dr. Crovetti of Marquette University's Civil and Environmental Engineering Department. With Dr. Crovetti's help, the physical placement of each cell was determined and located on site under his supervision (M. Bratzke, personal interview, December 7, 2010). As these instrumentation items were known about and chosen very early on in the construction process, this coordination effort allowed the earth pressure cell installation to be coordinated with the footing excavation and concrete activities and finished in a timely fashion prior to any other critical path items becoming affected (B. Baenen, personal interview, December 15, 2010).

No special training or installation issues were noted for the installation of the earth pressure cells from any of the project team members.

3.6.2 Strain Gauges

Everyone interviewed agreed that the strain gauge installation did not impact the construction schedule. In fact, the installation did not influence the construction process at all (G. Sullivan, personal interview, November 29, 2010). As the strain gauge sensors had been planned for and ordered early enough in the construction process such that they would not affect the critical path items (M. Bratzke, personal interview, December 7, 2010), their delivery and installation became a “just in time” type of construction activity. The sensors were delivered and arrived to the DLC site on time and were then installed shortly after their arrival. This allowed for very little, if any, impact to the construction schedule (D. Nash, personal interview, November 29, 2010).

The electrical contractor had to undergo special training regarding the use of a specialized welder for the installation of the strain gauges (Vishay Strain Gauge Welder, Model 700). This welder is shown in Figures 3.6.1 and 3.6.2. This training was coordinated by Dr. Foley from Marquette University’s Civil and Environmental Engineering Department with the electrical contractor’s Superintendent and field personnel (M. Bratzke, personal interview, December 7, 2010). Dr. Foley also created the dimensioned sensor location drawing, with sensor heights and sizes, and reviewed it with the electrical contractor before installation (G. Sullivan, personal interview, November 29, 2010).



Figures 3.6.1, 3.6.2: Vishay Portable Strain Gauge Welding/Soldering Unit, Model 700[11]

Overall the installation of the strain gauges went well, but one difficulty which was encountered required the electrical contractor's field personnel to use a grinder to remove the outside layer (mill scale) on the steel beams in the sensor locations exposing the bare steel of the beams. This ensured the sensors would be properly welded to the beams when welded in place. During the original interviews, the electrical contractor's Superintendent mentioned a potential issue, still not addressed but that may occur, in attaching the cable to the sensor due to the small wire diameter; this was to be reviewed at a later date (G. Sullivan, personal interview, November 29, 2010). Through the second set of interviews, it was learned that the potential strain gauge cabling problem was not an issue. The strain gauge wires are planned to first be connected to a data acquisition device, and then be tied into the Metasys system (B. Bonczkiewicz, personal interview, February 28, 2011).

[11] This welder can be found at: http://www.vishaypg.com/docs/11302/700.pdf

3.6.3 Anemometers

As the anemometers had not been selected, and therefore not installed at the time of the interviews, consideration of how these instruments may impact the construction schedule could only be anticipated. It was determined that the anemometers could be installed at any time without significantly impacting the schedule. (M. Bratzke, personal interview, December 7, 2010).

No special training or installation issues were anticipated at the time of the interviews for the installation of the anemometers from any of the project team members.

3.6.4 Non-Specialty Sensors

Although the non-specialty sensor installation had not begun at the time of the interviews it was not anticipated that there would be any impact to the construction schedule because these items are already built into the construction sequence. It is the task of the mechanical contractor to ensure that these devices follow the rest of the mechanical installation schedule. It is predicted that scheduling impact, if any, would be in ensuring the design-build contractor for the building automation system/temperature controls delivers their equipment to the jobsite in time to meet the construction schedule.

There are always shop drawings required for mechanical equipment. These drawings are completed by the design-build contractor for the building automation system/temperature controls and submitted to the mechanical contractor to be reviewed to ensure that what has been specified in the drawings is what was designed. The drawings are then sent to both the owner and design-builder for approval. Once the drawings are approved, the equipment can be installed at the appropriate time in the construction sequence. The special training that accompanies this type of equipment and sensors is completed at the end of the project as a transfer from the construction team to the operational team. Generally, the entire mechanical construction team and equipment suppliers meet with facilities representatives from the university to complete the commissioning process and provide a walkthrough of the whole system. This walkthrough trains the university personnel in the operation of the mechanical systems and is usually completed over a one-day period. If the system is large, or scheduling conflicts arise, the walkthroughs and training sessions may span of several days.

As these non-specialty sensors are commonly installed and used devices, especially on Marquette University's campus, it is not expected that there will be any difficulties in their installation. The only challenge foreseen regarding the mechanical equipment on the project is the aesthetics of all the installed mechanical systems and their sensors because the majority of the building has exposed ceilings, an unusual concept as compared to a standard building project. Most buildings have dropped ceilings below all of the mechanical equipment so the installers generally do not have to worry about how the equipment looks, just how it works. In the DLC, the mechanical equipment and non-specialty sensors will need to be installed in ways that do not appear to be disorganized and chaotic because the majority of the equipment will be exposed to patrons of the building (R. Kwiatkowski, personal interview, December 15, 2010).

3.6.5 Analysis of Instrumentation Construction Schedule Effects and Specialty Training

The specialty instrumentation installed in the DLC project did not have any impact on the construction schedule. Although Marquette University did not experience any construction schedule effects, future project teams must manage the construction schedule proactively with a focus on the incorporation of specialty instrumentation into the project schedule. Ensuring the specialty instrumentation in selected, ordered, and delivered prior to the critical milestones associated with each device's installation is the best way to ensure each device in installed without negatively impacting the overall construction timeline. To establish firm timelines for each instrument's installation requires the use of a specific instrumentation items list prior to creating the general construction schedule and to establish each specialty device as an activity within the overall project schedule. This will help project teams communicate the installation schedule for each device within the project schedule, allowing those involved in purchasing and calibrating the instruments prior to installation to determine how much time is available for these activities. Establishing firm timelines for all specialty devices, and communicating these timelines to all project team members, also allows for any specialized training required to be included in the schedule and ensures completion of these activities prior to installation

3.7: Displaying Data Collected in the DLC

Displaying both static and live data collected in the DLC is one of the main goals behind the living learning idea and function of the building. Many team members were able to comment on how this will be accomplished, and contributed ideas regarding how the display will look. These team members include Marquette University's ITS Project Manager, Marquette University's College of Engineering Computer Systems Manager who represents all of the technology integration from the college, the Project Manager for the building automation system/temperature controls, the Project Manager from Marquette University's Office of the University Architect, and Marquette's University Architect.

3.7.1 How the Data Will be Displayed: the Kiosk System

Some of the data collected from both the specialty and non-specialty sensors are anticipated to be displayed on what is known as a kiosk, which is a public information station. Kiosks are designed to provide relevant information to users, and these stations will be a touch screen, interactive way for users to navigate through select data collected in the DLC. An example of a person interacting with a Johnson Control kiosk is shown in Figure 3.7.1. These devices are often used in LEED certified buildings to display the energy consumption and green production information (S. Wrenn, personal interview, March 1, 2011). The DLC design and construction teams anticipate obtaining LEED points for installing kiosks in this project as well.

Figure 3.7.1: Interacting with a Kiosk at the Johnson Controls Corporate Headquarters

Through the second round of interviews it was learned that kiosk system design is still in progress, but for the portion of Phase I that will open for use by the College of Engineering in August of 2011 one kiosk is planned to be installed on level one on the same wall as the elevator (B. Bonczkiewicz, personal interview, February 28, 2011). Although only one kiosk is to be installed initially, the interactive display idea will also have an online component from the start. With the online component, any user will be able to go online and view the static information and live data that will be displayed on the kiosks in the DLC (E. Hendrickson, personal interview, February 25, 2011).

The information screen display is still being discussed and is in the design phase. The original idea was to show a “dashboard” kind of display, much like a dashboard in a car (T. Ganey, personal interview, November29, 2011). Touring the Johnson Controls corporate headquarters in Milwaukee, Wisconsin, and seeing how they use kiosks in their facility helped to give various design and construction team members a better idea of how the DLC could display information. Two examples of how the kiosk can display information are shown in Figures 3.7.2 and 3.7.3. A goal of this kiosk system is to ensure that it is very intuitive and user friendly. It is desirable to have these devices at an information level that is able to be used and understood by anyone who walks into the building, allowing them to learn from it (M. Jahner, personal interview, November 23, 2011).

Figures 3.7.2, 3.7.3: Example Kiosk at the Johnson Controls Corporate Headquarters

3.7.2 How the Kiosk System Works

The kiosk system is a server-based system (S. Wrenn, personal interview, March 1, 2011) which gathers all the information from the sensors installed in the DLC to display the data in an interactive way. All the instrumentation devices installed in the DLC will either tie directly into the Metasys system or will be tied into a data acquisition device which will then transfer to information to the Metasys system. The kiosk system pulls the data collected from the Metasys system and displays it in any way the customer desires (B. Bonczkiewicz, personal interview, February 28, 2011).

3.7.3 The Information that Will be Displayed on the Kiosks

The exact information that will be displayed on the kiosk, and the online component, is still being determined (B. Bonczkiewicz, personal interview, February 28, 2011). Currently the plan is to display some of the building's MEP system performance data, some of the information from both the strain gauges and weather stations to show the effect of the environment on the structure (S. Wrenn, personal interview, March 1, 2011), as well as some of the static information relating to the green features of the building (E. Hendrickson, personal interview, February 25, 2011).

3.7.4 How the Cost of the Kiosk System Installation was Determined

At the time of the second round of interviews, the cost of the kiosk installation had not been determined (S. Wrenn, personal interview, March 1, 2011) because the scope of what living learning components will be incorporated into the kiosk system was still being defined. Items that will need to be evaluated in the cost determination include: component cost, screen costs, cost of the application server, as well as the cost associated with the design-build contractor for the building automation system/temperature controls software development (E. Hendrickson, personal interview, February 25, 2011).

3.7.5 Challenges Related to the Kiosk System

Two main comments were given related to the challenges of the kiosk system. The first challenge stated was determining what information to display in the DLC. With the wide variety of data being collected in addition to all of the information regarding the green aspects of the building, there are many options from which to choose. There also have been discussions regarding displaying information from within the individual laboratories in the DLC, which could create other questions regarding the choice of information from individual laboratories that is relevant and important to display throughout the building on the kiosk system (S. Wrenn, personal interview, March 1, 2011). The second challenge identified during the later interview period was that the technology management focus to that point had been on the installation of the sensors themselves, with less emphasis on the use and display of the data that would be collected. The kiosk display and use discussions simply had not advanced sufficiently to identify the challenges that would be presented in the process (B. Bonczkiewicz, personal interview, February 28, 2011).

3.7.6 Analysis of Displaying Data

The kiosk system being implemented in the DLC is a very innovative way to combine the data being collected and will be a valuable tool in generating interest in engineering through interesting, fun, and interactive way to see engineering on display. It is advised that a specific list of items to be displayed be generated early in the construction process to ensure an adequate amount of time is provided for those developing the design of the kiosk display. The instruments installed can collect a large amount of information, and determining what data is of interest for inclusion in the display is an important aspect of the kiosk system. Much like the instrumentation effort as a whole, it is important to establish an adequate budget for the kiosk implementation at the beginning of the project to ensure the number of displays desired can be included.

3.8: How the Sensors/Instruments Will be Maintained in the DLC

At the time of the initial interviews, there were still some questions outstanding to determine exactly how the instruments in the DLC would be maintained. Nevertheless, it was stated that there are two types of maintenance that will need to be performed to maintain the instruments: physical and electronic. Therefore, the maintenance will most likely be a joint effort between the College of Engineering, Marquette University's Information Technology Services (ITS), and Facilities Services.

The College of Engineering will be in charge of collecting and manipulating the data from the sensors to become useable information for students and researchers. ITS will be responsible for the technical aspects and programming of the sensors as well as being in charge of the display of the data through the kiosk system (T. Ganey, personal interview, November 29, 2010). Facilities Services will be accountable for the sensors and equipment that are necessary for running the buildings. This would include the piping and wires for the sensors and the non-specialty sensors discussed at length in this thesis (M. Jahner, personal interview, November 23, 2010).

Although the maintenance of the sensors themselves will not be of concern for ITS, the two servers that provide information to the kiosks and Metasys will need routine maintenance, such as program patching and upgrading, to ensure they are up to date, working properly, and remaining secure (E. Hendrickson, personal interview, February 25, 2011).

3.9: Information Regarding the Instrumentation that Would be Valuable to Know Earlier in the Construction Process

Collecting information through the interview process resulted in a compilation of insights regarding possible improvements in instrumenting a building of this type. Information that would have been beneficial to know prior to the start of the different phases of construction is outlined below.

In a broad sense, having a specific list of all of the instruments that are to be installed for the facility from the beginning of the design and building process would be a significant help in determining the budget for the instrumentation portion of the project. This would allow the instrumentation activities to be better managed from the beginning of the project and tie the sensoring into the building design in a more thorough way (B. Baenen, personal interview, December 15, 2010). In addition to establishing a specific list, having the full commitment of the building owner and allotting a provision of time for faculty to properly develop plans for sensor installation and use within the completed project would be beneficial as well (C. Foley, personal interview, April 10, 2011).

A planning and design suggestion would be to identify the needed large exterior equipment, such as anemometers, or weather stations, well before construction begins. This would allow for more architectural design and review to place these devices in discreet locations or incorporate specialized design features to make these installations blend into the overall design as much as possible. The large towers intended to be installed on the DLC may look out of place because the desire to install anemometers and weather stations was not brought to the design and construction committee in time to do any architectural design or revisions to make them a part of the building design (M. Bratzke, personal interview, December 7, 2010). It should be noted, that although it would be nice to try and incorporate large items, such as weather towers, into the architectural design, the engineering needs directly create conflict with this idea. To obtain the data desired, these devices will always look like an after-thought (C. Foley, personal interview, April 10, 2011).

Several team members mentioned knowing more information regarding the information to be displayed on the kiosks would have been helpful to know earlier in the project planning phase. Having an earlier start on creating a list of the desired information to be displayed at the end of the project through the kiosk system would have been helpful in identifying control points within the equipment that have sensors installed in them. (R. Kwiatkowski, personal interview, December 15, 2010). Having an increased understanding of the expectations for the end result could also help those installing the sensors to better serve their customer. With a deeper understanding of desired end result the contractor performing the installation would have the ability to provide better suggestions on placements, different installation techniques, or potential ways to save money on the project; much like the contractor would do to serve their customer in a standard project without specialty sensors (M. Lochman, personal interview, November 30, 2010). Without the final results or a specific vision in mind, assumptions had to be made on the wiring of some of the devices. Doing this may have caused different sub-contractors to either over-state or under-state their instrumentation budgets because they did not have more specific instructions for the data collection at the time the installation was completed (M. Bratzke, personal interview, December 7, 2010).

3.10: Project Delivery Method Comparison

Marquette University's DLC is being constructed using the design-build project delivery method, but other instrumented building projects may be constructed under different project delivery methods. This section outlines the general benefits and risks for several project delivery methods, and provides a recommendation on the suitability of that delivery method as a reasonable choice for another instrumented building project.

3.10.1 Design-Build

Generally, design-build projects have benefits which include: using a sole source for the design and construction, early cost commitment by the contractor, enhanced collaboration among the project team, enhanced control of the project budget and schedule, generally reduced claim costs, and can be a good fit for projects with innovative designs if the owner is willing to be involved to ensure the specialized program requirements will be completed in a satisfactory and timely manner. Common risks associated with using the design-build method of delivery include: concentrating risk in a single source (the design-builder), increased risk of determining the owner-designed criteria behind the initial scope and preliminary design which is essential in the success of a design-build project, having the overall quality of the project suffer and design be incomplete, and increased contractor contingencies (CMMA, 2008).

Overall, the design-build method is a good choice for instrumented building projects. This method has worked fairly well for the instrumentation implementation at the DLC. One positive aspect of using the design-build delivery method for Marquette University was that the university was able to work with a firm that has previously constructed several design-build projects on campus. Therefore, the University representatives knew that the contractor chosen was a trustworthy firm that would perform to the high standards of Marquette University. As design-build projects allow for design to continue as construction begins, being in the midst of discussion regarding some of the instrumentation items did not impact the project in the design phase. Thus far, the project is progressing on schedule and the instrumentation is being installed within the schedule and budget established which allows for the project to meet the goal of using specialized instrumentation in the College of Engineering curriculum.

Although the DLC instrumentation effort has been progressing reasonably well, there have been some challenges associated with using the design-build method. One major complication associated with the instrumentation installation in this project was determining when each item had to be installed within the already established construction schedule without affecting the overall timeline. As the design and collaboration continues after the construction starts, communication associated with the windows of opportunity for installation occurred at the last-minute, causing some frustration for those involved in the instrumentation effort. For example, although the earth pressure cells desired for installation in the project were selected, they had to be rush-ordered because the purchaser was not informed that the window of opportunity for the installation was much sooner than they anticipated. This was a gap in communication relating to the project schedule. Another example demonstrating the scheduling issues relating to specialty instrumentation involves the anemometers on the project. Had the locations or exact items being purchased been known prior to installing the roofing membrane, the installation of brackets for the weather station towers, or the towers themselves, could have been completed to avoid having the roofing contractor return to site, saving both time and money on the project.

Marquette University fortunately is completing the DLC project in two phases, which allows for the lessons learned on the instrumentation efforts in Phase I to be used to improve the instrumentation efforts on Phase II.

3.10.2 Design-Bid-Build

The design-bid-build project delivery method is another likely method chosen on university campuses. Benefits of this delivery method include: widespread use and familiarity with the process, checks and balances on the design because the designer and constructors are separate entities which leads to clearer delineations of roles and responsibilities for team members, the owner is more actively involved in the project, and the owner has greater control over the end product as the facility’s features have been determined before selecting a contractor. General risks associated with design-bid-build projects include: having a long and linear process of design and construction, not knowing what a project will cost until design is complete and a contractor is selected, having the architect design the project without contractor input creating less overall cooperation between the designer, contractor and owner, delay in one phase can delay an entire project, various cash flow risks and lien management techniques, and potential of hurting the owner due to long term lead items and risks of inflation (CMMA, 2008).

The design-bid-build project delivery method could work for a building project emphasizing a well-developed instrumentation effort. The wide spread use and familiarity of this delivery method would create a fairly easy construction process that would allow the owner's building and instrumentation goals to be met as long as the means, methods and materials were well known and properly described in the contract documents. The disadvantages of using this method would include the longer time necessary for design and construction of the facility, not knowing the costs of the project until after the design and contractor selection is complete, and not having the overall cooperation and collaboration a design-build project would have.

3.10.3 Multiple Prime Contracting

Multiple prime contracting is a project delivery method where an owner contracts directly with several contractors rather than with a single, prime contractor creating a situation where the owner essentially acts as the construction manager. General benefits associated with this project delivery method include: having a larger pool of qualified specialty trade contractors, the possibility for fast-tracking which can benefit projects where time of performance is critical, the owner has control over the specialty contractors, there is control over bid shopping, and avoiding general contractor mark-ups on subcontractor bids through owner-direct purchases of major materials. Risks associated with multiple prime contracting include: the final cost of the project is not determined until the final prime contractor is selected, increased amounts of time needed during bidding, project management and coordination costs increased, increased communication issues, lack of overall authority and coordination once construction is underway, unreliable cost estimates, the owner is not relieved from coordination through delegation, inadequate project quality, and increased vulnerability to project delay and interference claims (CMMA, 2008).

Although the multiple-prime contracting delivery method allows for a larger pool of qualified specialty trade contractors to be used directly by the owner, overall this project delivery method would prove inadequate for a project emphasizing a large specialty instrumentation effort as the risks associated with this delivery method would out-weight the benefits. Not establishing an overall budget until the final prime contractor is selected and having unreliable cost estimates would be detrimental for a project implementing specialty instrumentation. Not knowing the costs required within the project would make it very difficult to establish and retain a good budget for the instrumentation, thus likely increasing the number of change orders associated with these tasks. The risk of needing to allocate the funds on reserve for the instrumentation efforts of the building to be used for the structure itself seems much higher a risk with this method, which would directly conflict with the initial instrumentation goals of the project. Having the owner directly involved in the coordination of the construction effort and having the high risk of communication issues also deem this delivery method to be insufficient for a project involving a large specialty instrumentation effort. These insufficiencies in the project delivery method could cause the instrumentation to have a better chance of being overlooked, not installed in the proper sequence leading to additional costs or time needed for the project, and for the instrumentation to not be communicated well among the prime contractors leading to confusion, frustration, and direct conflicts in the construction process.

3.10.4 Construction Manager at Risk

The construction manager at risk project delivery method is similar to the traditional design-bid-build project delivery method in that the construction manager acts as the general contractor during construction, but also provides professional management assistance to the owner during project planning and design. This delivery method has general benefits which include: engaging the contractor before design is complete, offering the opportunity to begin construction prior to completion of the design by negotiating a guaranteed maximum price based on a partially completed design, clear delineation of roles and enhanced communication, and providing beneficial assistance to owners with less experience in construction management. The general risks associated with using the construction manager at risk form of project delivery are similar to those associated with the design-bid-build approach: generally having a longer, linear process of design and construction, not knowing what a project will cost until the majority of the design is complete, delay in one phase can delay an entire project, various cash flow risks and lien management techniques, the potential of hurting the owner due to long term lead items and risks of inflation, as well as reduced owner control (CMMA, 2008).

Using the construction manager at risk project delivery method should work for an instrumented building project. Having a contractor that performs construction management duties during programming and design phases and who also constructs the actual facility is a desirable characteristic of this delivery method. The fact that the designer and contractor would have a better shared understanding of how the instrumentation would be incorporated into the design would allow for the contractor to schedule the specialty items into their general construction schedule and ensure the sensor placement and design are being incorporated in a constructible manner. By using this method, the project potentially has the ability to be fast-tracked which may be desirable to an owner, is advantageous to the owner who has less experience with construction, and places the construction manager in the design process leading to constructability reviews which can enhance the overall construction and instrumentation process.

Chapter 4: Conclusion/Recommendations

Based on the insight gained through the process of writing this thesis, several conclusions and recommendations can be made that will benefit the next design and construction team challenged with an instrumented building project for the purposes of education similar to Marquette University's DLC.

It is important for those involved in developing a similar instrumented building to investigate other instrumented building projects that were completed with the intention of being used for enhancing student education rather than for safety or pure research. Knowledge of the structural elements and other items that the University of Colorado at Boulder and Marquette University have chosen to instrument and collect data from can help the next team start their discussions of what they would like to measure, and give them the opportunity to discuss what instruments they believe will be useful for their building. Thoroughly analyzing projects which were completed with similar instrumentation goals also will give the next construction team an opportunity to be informed about the items presenting challenges for the other project teams, be aware of how these challenges were handled, learn of any installation limitations the team may have been confronted with, be prepared to deal with similar issues, and possibly determine ways in which to avoid problems faced by other project teams in their instrumentation efforts.

It is also important for any owner to thoroughly review and determine what project delivery method to use in the building of their project. The owner needs to determine a realistic budget that includes appropriate budget allocations for the instrumentation effort, consider the project and design goals, determine an appropriate schedule available for the project, and asses the risks associated with the project delivery methods being considered. Based on the analysis in "3.10: Project Delivery Methods", the project delivery methods that would be suitable for an instrumented building project similar to Marquette University's DLC project include: design-build, design-bid-build, and construction manager at risk.

The construction project team must take several steps to manage their project properly and meet their objectives. First, they must determine whether the instrumentation effort is an important goal of the project and if so, then the team must commit the resources and the planning. They should include tasks to analyze and discuss similar projects and identify the items the team believes would be beneficial to include in their project. Establishing what the instrumentation effort includes and how it will be incorporated into the entire project will help the project's construction and design team determine which instruments will be included in their project, create a specific list of the desired items, and allocate appropriate funding. Committing to the instrumentation effort and establishing a specific list of specialty instrumentation items early enough to be incorporated as activities in the general construction schedule will allow all team members to be aware of when all installations are planned which in turn could alleviate any confusion or frustration relating to the timelines associated with each specialty item. Installation scheduling ensures all construction and design team members are aware of the timelines they have to choose the specific sensor(s), order and receive the products, perform any special training necessary for the installation, confirm the selection of any large external instruments to be incorporated in the project, determine whether any architectural design is affected by the installation, and ensure all instruments are delivered in time to be placed in the project. Early commitment to the instrumentation effort in the design phase of the project also ensures nothing is rushed or installed last minute. Ensuring the instrumentation effort is a priority creates the opportunity for well-established budgets, all-inclusive designs, and realistic and workable project schedules.

Another important aspect to any instrumentation effort is completing a quality control review of the instruments purchased before installing them in the structure to ensure they will collect reliable data. Early commitment to the instrumentation effort and establishment of an installation timeline for each instrument in the project allows those involved with purchasing the instruments to complete the thorough series of pre-installation tests and calibrations required by many of the sensors. Performing a pre-installation calibration routine confirms the instruments will perform as expected prior to installation. If the pre-installation calibration tests do not acquire the data expected, the owner may have the time and opportunity to perform further testing, contact the manufacturer with questions, or determine a way to acquire the data anticipated.

It is also important to understand how each instrument will be installed in the project. As many of the specialty instruments may require delicate installations, barriers to the physical placement of the sensors should be understood prior to their installation. Legal provisions or work rules might determine which persons are able to complete the physical installation. For instance, the design and construction team should know prior to installation of each device if the contractors on the job are required to install any of the sensors purchased because the process falls under their union jurisdiction. Alternatively, specific faculty or design team members may be allowed to do their own installation. If the contractors on the site are required to do the installation and it is believed that specialty training or discussions with the installer is required prior to installation, time to schedule these pre-installation meetings will be available. Determining early who is installing what and if specialty training is necessary prior to placement will help to relieve any concern or frustrations of inadequate installations.

Designating one person as the champion for all instrumentation efforts within a project team will also help the next team design and build an instrumented building. The instrumentation champion would be the main source of knowledge on the entire instrumentation effort, have a working list of all sensors to be installed in the building, and be aware of any problems or issues regarding these devices. This person would also be the person to collect all of the instrumentation ideas at the beginning of the project from the faculty, staff, and other design team members, organize the information into a cohesive list, and serve as the representative from the college regarding all instrumentation matters. It could be argued that the overall instrumentation champion for the Marquette University DLC project was not incorporated into the project until about half-way through the construction of Phase I. The Project Manager from Marquette University's Information Technology Services took control over of the entire instrumentation effort. After bringing this project manager into the process, two noticeable differences were seen in the instrumentation process: it was easier to contact this single person with questions regarding the various instruments installed or being considered for installation, and more efficient and functional instrumentation project meetings were performed. Based on this experience, it would be very advantageous to any project team to appoint the instrumentation champion early.

It should also be mentioned that the instrumentation champion during the design and construction may not be the same person who actually maintains the instruments once the project is complete. If this is the case, it is important to connect the design and construction phase instrumentation champion with those who will maintain the instruments after the project is complete. This installation and maintenance hand-off will help answer any questions regarding how the instruments were installed, create a roster of vendors for the products purchased for future reference in the event that further questions arise about the sensors themselves, and ensure the person maintaining the system understands what to expect from all of the specialty instruments. If there is not a specific person who is designated to maintain the products prior to the start of construction, it would be advantageous to either appoint that person or hire a staff member with the job description including a high level of commitment to maintaining the sensors in the project. Because there are a large number of different sensors being installed, having someone to manage all of these instruments will be necessary to ensure the instrumentation and data collection efforts do not falter.

Another recommendation that would benefit the next team designing and building an instrumented structure would be to incorporate the experts on the products and systems being installed into the instrumentation project meetings. Inviting manufacturers, system designers, and engineers who have a greater working knowledge of the instrumentation products being installed can help the faculty, staff, and project team members increase their knowledge of what is being installed, identify options and alternatives available, improve the quality and efficiency of the project meetings, and help to ensure adequate and accurate designs and installations of the instruments. It should be noted that incorporating these experts into the project meetings might not work until the point where instruments were selected and consensus reached on the measurements desired because the project may not be advanced enough until then for their consultation in design and installation to be of value.

For teams considering the use of a building automation system to measure and collect data in their project, it is important to review multiple options before selecting a vendor for their project. Although Marquette University has built a relationship with a local firm, Johnson Controls, there are other options worth exploring. Based on the research done to complete this thesis, products and services provided by Honeywell seem comparable to those provided by Johnson Controls; Honeywell may be a better choice for the next design and construction team looking to use a building automation system to collect data in their project. Although product information provided by both firms through their websites and pamphlets may give customers a general idea of what products and services are available, contacting both firms to bid on their project and also speaking with other customers who have worked with each firm would be beneficial for the next team in choosing which vendor to use.

For other project teams considering the use of anemometers installed on rooftop weather stations on their project and are not sure of the exact items desired for measurement, one recommendation for them to consider is implementing several different kinds of anemometers on the rooftop weather stations. The purpose of the weather station installation is to collect data about wind to teach students how weather can impact a building's structure and performance. Using several different anemometers could demonstrate how the data varies among anemometer types, and from the data collected, discuss and learn why different anemometers may be the preferred data collection tool for a particular project. Installing varying instruments would add another element to the living learning idea that is the foundation of the instrumentation effort.

For the Marquette University team that will be involved in the instrumentation efforts of Phase II, many of the above recommendations are applicable before starting discussions of what sensors to implement in the rest of the DLC. Reviewing the experience of purchasing, installing, and using the instruments from Phase I will be the best place to begin. Analyzing the portions of the instrumentation process that were difficult will help to determine what should be changed, omitted, or added to improve this effort in Phase II. Having a champion of all of the instrumentation will help to relieve communication issues, ensure nothing is being left-out or forgotten, and will establish a specific and well thought out list of items to be included before beginning design and construction. Although Phase I was completed in a depressed economic and construction environment, re-committing to the instrumentation effort and establishing an appropriate budget for the purchase and installation of the instruments will help to get the most out of the instrumentation installed and create the best possible learning experience for future Marquette University engineering students.

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Appendix A: Structured Interviews

APPENDIX A: TABLE OF CONTENTS
In order of date and time interview completed

Structured Interview: Mike Jahner (11.23.2010, 8:05am-8:59am)

1. **What is your role at Marquette?**
   Project Manager (doing interview from an OUA stance—will be transferring over to Facilities Services, but don't know anything about that department's view yet)

2. **What was your role in the instrumentation of the DLC building project?**
   Taking faculty suggestions/ideas

   Working through the feasibility of them

   Implementing the ideas as needed/appropriate

3. **Which sensor(s)/instrument(s) did you select?**
   n/a

4. **How did you determine which sensor(s)/instrument(s) were correct for this application?**
   Based off of faculty suggestion

5. **What can this sensor/instrument measure?**
   n/a

6. **What are we intended to measure?**
   n/a

7. **How should the information screen look on the MetaSys readings?**
   Very intuitive and user friendly

   "Idiot proof" → essentially be pictures

   Touch screen/interactive device so anyone could look at it and hone in to one area

   Driven to teach… but in a way that anyone could walk up to it and use it

   - **Are there other presentation / data manipulation software that will be required to best utilize / present the data?**
     Don't know the answer to that… n/a

     Everything Jahner would look at, MetaSys can do…

8. **How often should readings be taken/updated?**
   Everything on MetaSys is real time—it's all what's happening now
   Think the question should be, how much data can we store for trends? Or should we store? With MetaSys can do every minute if you wanted to… usually do every 15 minutes… depends on how much data you need/want

Depends on what you want to do with the information

- **Are there specific environmental conditions (wind / rain / snow / locusts) that are of particular interest?**
  EVERYTHING is of particular interest

  Internal temp doesn't mean anything w/o external temp

  Weather info from roof allows us to look at pressurization issues (ie—if its really cold on one side of the building, we can look at the wind info and see why that might be)

9. **How will the data be used?**
   I don't know—I would predict for building energy usage (from Jahner's end)

   - **Is there any data "Cleansing" that is expected**
     Don't know what "cleansing" means

10. **Why will this data beneficial to the college of engineering program?**
    Will be able to see what a building does

11. **How was the location of the sensoring equipment chosen?**
    Faculty chose for specialty sensors

    For me, it's by HVAC design (thermal performance, energy usage—aka VAV boxes, thermostats, motors, electricity in, steam in, chilled water in…)

12. **How much time was spent in analyzing sensor/instrument options for this application?**
    n/a

13. **Which options or products were formally evaluated?**
    All the products Jahner is looking at is Johnson Controls products; which are commonly/already used on campus

14. **If there was a different sensor/instrument that would have also worked for this application, why did you choose the one(s) that were installed?**
    Chose because that is what we have across campus

15. **Would you have liked more time to research options before making your selection?**
    No

16. **Have you seen sensors/instruments like the one(s) you chose used in applications elsewhere before? If so, where?**
    Yes, typical building automation systems have these all over the place (*note, stuff Jahner is looking at is NOT specialty stuff)—this is what we put in every building, but

now it “sexy” for some reason…

17. **Have you seen other instrumentation applications (at other universities / etc) that would have been of interest to have installed at the DLC?**
    We’re doing everything we’ve done in other places—the key in DLC is the user interface
    - *at this point looked at MetaSys to see how the graphical view is on a standard building (see JPEG sent from Mike) → Jahner expects that the graphical views used at the DLC will be more user friendly (less abbreviations or explanations of what they mean, etc)
    - *perhaps half the screen w/ the MetaSys graphics and on the other half an actual picture of the object monitoring/area being sensored…

18. **What prevented those from being considered?**
    We’re doing pretty much everything Jahner wanted to do… I’m sure there are other things that could have used, but what we’re doing will be a good representation of this area and to get students interested

19. **What instrumentation should be included in Phase II of the DLC construction**
    Match what we’ve done in Phase 1

    We might do boilers instead of steam—so have comparable measurements—can have more info for boilers, so measure all the parts on the boilers

20. **How has the instrumentation on this project been managed?**
    Overall, the ideas/suggestions have come from the college—and the construction team has put in everything that they needed to make it work

21. **How will the instruments and sensors on this project be maintained?**
    This is an interesting one. Pretty much facilities will maintain all things that they need to run and operate the building; but most likely won’t maintain the structural sensors or wind sensors b/c they imperative to make the building work…

22. **Who owns the data that is collected?**
    Marquette

    Everyone can see it, everyone can track it…. Whoever has access to it can use it. For example, if Crovetti ever leaves, he shouldn’t be able to take the data with him

23. **Who is in charge of maintaining the sensors/equipment that runs the sensors?**
    Facilities for what are necessary to run the building; would assume the college would maintain the specialty sensors…

24. **In the instance that the faculty who chose these sensors (Crovetti/Foley) leave, how will this testing continue beyond when these faculty are on staff?**
    No idea… would assume they would post a position for their replacement who is also interested in this same type of research?

25. Sensoring a building for the sole purpose of learning has not been done to this scale before; what were the reasons behind this decision?
Because it's cool!

Learning!

The engineering college is building a new college, why wouldn't you do it? Its engineering on display! It's the way to get kids interested in learning about it.

26. Does MU's use of the term – "Discovery Learning" impact the decisions made relative to instrumentation?
It's basically everything that they're doing—its making sure that anyone can look at anything and learn what's going on. Next step is taking what we put in and making it easy for a novice to learn/get something out of it (get a "oh, that's kind of cool" out of them)

27. Have you seen other instrumentation applications (at other universities / etc) that would have been of interest to have installed at the DLC?
n/a

Structured Interview: James Crovetti (11.23.2010, 2:05pm-3:10pm)

1. **What is your role at Marquette?**
   Associate Professor and Researcher, Director of Transportation Research Center, tenured faculty, research focuses on pavement materials/design/performance/construction (structural side of transportation)

2. **What was your role in the instrumentation of the DLC building project?**
   One of champions for instrumentation of the building (advocated for sensors/making it a learning lab, reminded design team about instrumentation)

   When the time came to actually do something, because of my soils/foundations area which is one of the first areas to be built → role was to get the ball rolling on the instrumentation—1st one to select sensors

   Lesson learned: should be talking about instrumentation from day one! Make sure you set aside the appropriate dollar figure, and don't skimp on sensors—design a system to the realistic $ value to start with (especially if we are going to call it a DISCOVERY LEARNING center or complex) so that the appropriate sensors can actually be bought and installed

3. **Which sensor(s)/instrument(s) did you select?**
   The earth pressure cells (from GEOKON)
   - These sensors can go anywhere you want them to go; they are typically 2 thin plates with a fluid between them….

   Go to GEOKON.com; product; earth pressure cells; we used the ones that look like a big lollipop (when you see the pictures)

   We put in a total of 6 earth pressure cells; 2 went under foundations, 4 will be measuring earth pressures by the soils pit (exterior to the pit)
   - The sensors by the soils pit are in 2 sets of 2 sensors. Within the set, one measures the vertical soil pressures and the other measures the horizontal soil pressures; the pairs are located at approximately mid-height and the bottom of the pit—measuring at rest conditions
   - These sensors can probably pick up to within a couple of PSI…
   - Hope we can apply loads to the ground surface and see how these pressures affect the soil at different depths

4. **How did you determine which sensor(s)/instrument(s) were correct for this application?**
   In this particular situation, I knew we were looking for pressures and had used these sensors before and knew they were applicable

   Some of the details about these sensors: measure pressures by changes in fluid pressure changes; we bought systems that could measure in a dynamic pressure changes (because they can also measure static loads)—wanted a system that could measure a transient load…

One sensor is in an isolated spread footing and one is in a combined spread footing (carrying 2 columns with an x-bracing)

- the reason put in the combined footing was because either eccentricities being generated (ie wind loading)

5. **What can this sensor/instrument measure?**
Pressures; technically fluid pressure internal to the cell; but this can represent the ground pressure

6. **What do we intended to measure?**
At rest earth pressure in a granular soil

Foundation pressures/contact pressures between a reinforced concrete footing and lean clay soil

7. **How should the information screen look on the MetaSys readings?**
n/a- don't know anything about MetaSys

Would like to show cross-sectional view or a 3D iso-view, would want design loadings, design/applied pressures, and the actual pressure for comparison

    a. **Are there other presentation / data manipulation software that will be required to best utilize / present the data?**
    No—these sensors require a voltage in voltage out kind of thing… so just need to read the voltage out which get converted to a pressure with a simple formula

8. **How often should readings be taken/updated?**
For the ones reading dead loadings, recording every 15-minutes-every hour would be adequate (because the data is essentially flat-lined)

At Column G6 (which could have dynamic readings due to the cross bracing)—may go into 10 cycles per second for particular events (ie: logging a wind event) but otherwise the data will likely be read just every 15 minutes so the amount of data doesn't become overwhelming (until you get to 10 years or so…)

- We will likely end up discarding a lot since it will all be the same…

Note: all readings could be dynamic, but mainly at Column G6

    a. **Are there specific environmental conditions (wind / rain / snow / locusts) that are of particular interest?**
    Wind loading, potentially snow
    - Anything that changes the DL could be interesting…

9. How will the data be used?

For instructional purposes in the Geotech and Foundations classes

Not for other research at this point (with other sensors yes, but not this group)

a. Is there any data "Cleansing" that is expected

Yes; cut some out because the DLs are going to be the same

Not going to clean up the data just to make it presentable

For the data we have to date we are going to tie it to the construction process/sequence (we have been taking data from the time we installed the sensors under the footings so that we could tie the information to the construction process)

10. Why will this data beneficial to the college of engineering program?

The civil engineering program will benefit as far as understanding the design implications/process of foundations on soils

11. How was the location of the sensoring equipment chosen?

Wanted to instrument a footing

- Isolated spread footing; chose footing G4 b/c that was right on the corner of teaching lab (could have a display in the lab to show the footing loads)
- Combined footing is G6 & G7—which is on the edge of the same teaching lab

Tried to locate both in the lab and G6 because of the combined effects (versus having 2 isolated spread footings) because we could possibly see live load events from wind at the G6 location

All the wiring was brought to the middle at column G5 (which is in the EMST teaching lab)… so we can have a panel showing the live readings right in the teaching lab

12. How much time was spent in analyzing sensor/instrument options for this application?

Depends on how you look at it; could say zero for the building because I already knew about these sensors, but you could also say 10-12 hours from the prior application

13. Which options or products were formally evaluated?

Options were the type of plate and the type of sensor used for the plates

3 options for the plate configurations (thin-thin, thin-fat, fat-fat)

- Originally chose fat back (thin-fat) (model 3510) to measure pressures between concrete and soil (the ones under the columns)
    - o Thin on soil, thick embedded in the concrete footing during construction

- Then when we measured concrete on granular soils and granular soils on granular soils, got the fat-fat (model 3515) (for the soils pit) → gravely soils have more contact pressures, so needed a thicker plate, fat-fat spreads out the potential bias from localized contact forces (ie individual larger stones)

2 options for the sensing device (transducer or vibrating wire strain gauge)

Pressure range was another option—there are about 15 options—in general, you don't want to overload or significantly under-load these, so had to determine what pressures would be applied and choose the most appropriate (*more time was spent on this process, for questions #12)

14. If there was a different sensor/instrument that would have also worked for this application, why did you choose the one(s) that were installed?
Don't know of any other sensors really…

15. Would you have liked more time to research options before making your selection?
Could say yes, could say no; if say yes would I have used the time wisely? The decision making process just came at a bad/pretty busy time…

16. Have you seen sensors/instruments like the one(s) you chose used in applications elsewhere before? If so, where?
Yes, on the Marquette Interchange north leg

17. Have you seen other instrumentation applications (at other universities / etc) that would have been of interest to have installed at the DLC?
No

18. What prevented those from being considered?
n/a

19. What instrumentation should be included in Phase II of the DLC construction?
From the perspective of soils, would say similar kind of sensors

Backing up: originally asked for multi-depth applications (wanted another 16' down)—so we could look at more, deeper systems and the buildings effect on deeper soils
Another sensor type could be soil temperatures: could also look at frost penetrations

On the site (not the building necessarily)—we installed a pervious pavement in the Michigan Avenue Mall parking lot; right now don't have sensors in place, but will put them in the spring…intended in this case for storm water management…we're collecting rain water and sending it to the storm water system at a more controlled release; a detention system; collecting water at 3 level sources… checking water quality, survivability of pervious systems (clogging and maintenance needed to keep system active)…

-sensors at loading dock composite pavement sections (still to be designed and approved); want to put in asphalt to measure ambient temperatures/temperature gradient in the slab (creates a curve when top is hot/bottom is cold)—leading to a tension stress in the bottom of the concrete due to self-weight…which reduces the service life of concrete pavement… (really still phase I, but exterior to the building)

- here looking at measuring temperatures; showing benefits from having thermal barrier…

using roof of high-bay space above EMST lab as a outdoor space for demonstration park for alternate energies… essentially a park of displays of alternate energies, more so for home usages… help to show what is more effective for generating energy (ie: pinwheel versus turban/ vertical or horizontal spinning wheel) → something people can see, measure energy being produced

Addenda:

Saturday, March 26, 2011 2:34 PM, via email:

Simple Sample Calculations:

For the footings:
The allowable bearing pressures were listed as 10,000 psf = 69.4 psi.
We reviewed the plans and it looked as though the maximum applied pressures would be less than 60 psi.
I selected the Model 3510-2-400KPA Earth Pressure Cell which has a range of 0-58 psi (0-400 kPa) with an overload capacity to 87 psi.

For the Soil Pit:
The bottom of the soils pit is 8 ft below grade.
Assuming a backfill material with a unit weight of approx. 130 pcf, the maximum applied vertical pressure would be approx. 1040 psf = 7.22 psi.
I selected the Model 3515-2-100KPA Earth Pressure Cell which has a range of 0-14.5 psi (0-100kPa) as this was the lowest range available in the “Fatback” version.

Structured Interview: Dan Nash (11.29.2010, 9:09 am- 9:15am)

1. **What is your role on the DLC project?**
   Superintendent for the Opus Development Corporation which is part of the Opus Group

2. **What was your role in the instrumentation of the DLC building project?**
   To make sure that it goes in and goes in the right place

   To coordinate with MU faculty on placement

3. **Did you have any input into the type of sensors/instruments that were selected?**
   No

4. **How was the install of the instruments scheduled from your end?**
   Just the sequencing—after steel but before fireproofing—to make sure that it went in place

   Make sure went in the correct sequence of building construction

5. **How did you manage the instrumentation?**
   Didn’t

6. **How did you estimate the cost of the installation activities? Were the labor costs separated out in this estimate?**
   n/a

7. **What was the impact of these activities on the schedule?**
   Slim to none:
   - as soon as we got them we put them in
   - they got here on time, so they did not impact the schedule
   - “just in time”

8. **Were there any special training or shop drawings required?**
   Yes, the electricians had to be trained on how to weld it (structural sensors) and got drawings for where they were to be placed

   Note: didn’t do anything w/ the footing sensors b/c Crovetti came and placed those, just coordinated the timing

9. **Were there any difficulties in the install of the instruments? If so, what was it? Is there something that could have alleviated this issue?**
   None that Dan is aware of

10. **If you were to do another “living learning center” project which involved extensive instrumentation, what other information would you hope to have before starting?**
    Nothing really from Dan’s end—as long as get in time to sequence for construction

Doesn’t matter as long as it doesn’t impact his construction schedule

Let the customer/engineer figure out the other stuff

11. Is there any information you would have liked earlier in the construction process in regards to the instrumentation?
No

Addenda:

Thursday, April 14, 2011, via phone:

The general dates for the steel, concrete decks, and precast installation:
-steel was erecting from the beginning of June through mid-July
-the elevated concrete decks were poured from mid-July through mid-August
-precast concrete walls were installed from the end of August through the beginning of October

Structured Interview: Gary Sullivan (11.29.2010, 9:27am- 9:34am)

1. **What is your role on the DLC project?**
   Superintendent for Staff Electric

2. **What was your role in the instrumentation of the DLC building project?**
   Responsibilities include: Installation of the sensors and cabling

3. **Did you have any input into the type of sensors/instruments that were selected?**
   No

4. **How was the install of the instruments scheduled from your end?**
   We had to coordinate with the fireproofing to ensure we had them installed before the fire proofer got there

5. **How did you manage the instrumentation?**
   n/a

6. **How did you estimate the cost of the installation activities? Were the labor costs separated out in this estimate?**
   See Mick Lochman's interview

7. **What was the impact of these activities on the schedule?**
   Didn't impact really

8. **Were there any special training or shop drawings required?**
   Yes! They had to teach us how to use the welder

   The shop drawings located all the sensors on the beams
   - the drawings were all dimensioned (height, size of sensor, etc)

9. **Were there any difficulties in the install of the instruments? If so, what was it? Is there something that could have alleviated this issue?**
   Yes; had to use a grinder to remove the coating on the beams to get to bare metals so the sensors would adhere properly to the steel

   Issue we haven't had YET—haven't determined how we're going to attach to cable to the sensor at this point—it's to be reviewed at a later date. b/c of the small wire diameter…

10. **If you were to do another "living learning center" project which involved extensive instrumentation, what other information would you hope to have before starting?**
    Just locations… other than that we're good to go b/c we already did it once

11. **Is there any information you would have liked earlier in the construction process in regards to the instrumentation?**
    Same answer as #10!

Structured Interview: Tom Ganey (11.29.2010, 9:57am – 10:116am)

1. **What is your role at Marquette?**
   University Architect

   Leading the project team in construction and design

2. **What was your role in the instrumentation of the DLC building project?**
   PM for the overall project

   Facilitated all meetings regarding instrumentation

   Brought people together and am still bringing people together; we're not anywhere near done with this…

3. **How has the instrumentation on this project been managed?**
   I have tried to provide many opportunities for faculty to identify instrumentation opportunities

   Have worked with the construction team to identify methods of completing the instrumentation—that has involved numerous faculty members as well as the electrical contractor, the GC, some of the specialty contactors (ie- steel), and the project architect

4. **How was the location of the sensoring equipment chosen?**
   It has really been brainstorming—we've tried to collect ideas as people (both faculty and project team members) have thought of them up

   In the end, we made sure that faculty would have a use for the instruments before implementing them—if faculty saw it as a useful thing to record, we're pursuing it

5. **How will the instruments and sensors on this project be maintained?**
   TBD—we really don't know at this point… there is still some question if this is from the department's budget or the facilities budget

   There are different kinds of maintenance—physical and electronic
   - Electronic will be managed by college

   I would say it would be a joint effort of the college of engineering (manipulating the data that is gathered—collecting/using the data), ITS (technical/programming), and facilities services (pipe/wire)

6. **Who owns the data that is collected?**
   The college of engineering

7. **Who is in charge of maintaining the sensors/equipment that runs the sensors?**
   Sensors belong to the college

Equipment that supports the sensors belongs to ITS

8. **In the instance that the faculty who chose these sensors (Crovetti/Foley) leave, how will this testing continue beyond when these faculty are on staff?**
   I don't know…

9. **Sensoring a building for the sole purpose of learning has not been done to this scale before; what were the reasons behind this decision?**
   Not quite true: the University of Colorado project in Boulder that did this… they may have done this more so… there is some fear in the Colorado project that they did so much instrumenting that no one is maintaining it… *We have to be careful to not do our instrumentation beyond what is actually useable

   Reasons behind instrumenting the building: it's really probably 75% for teaching, and 25% for research—the thought is that for a class, in whatever discipline, to be able to see and use data from the building that they're studying in would be valuable; that they could apply some of the theory and practice based on what is available immediately from live data being collected

10. **Does MU's use of the term – "Discovery Learning" impact the decisions made relative to instrumentation?**
    No, the term doesn't mean anything to connect the two…

11. **How should the information screen look on the MetaSys readings?**
    At this point, the only vision that we have is that we're trying to created the "dashboard" effect… a MPH idea…

    We're trying to figure out what kind of dashboard to do…

    Trying to figure out: how should the screen will look? What units to measure things in (Btu? Gpm? Etc etc)

    a. **Are there other presentation / data manipulation software that will be required to best utilize / present the data?**
       I don't know… this would be interesting to know…

       Certainly any building automation system (BAS) could do this, this is something Dan Smith at ITS could answer better…

12. **Have you seen other instrumentation applications (at other universities / etc) that would have been of interest to have installed at the DLC?**
    No I have not

13. **What prevented those from being considered?**
    n/a

14. What instrumentation should be included in Phase II of the DLC construction?
I don't know—it depends on how Phase I goes

*** The biggest single challenge has been getting someone to own it from the college of engineering… there isn't a college entity/department that owns this thing and is the project client specifically – this has been frustrating! Whereas each lab has a sponsor/faculty member… the sensors have been getting input from a lot of people, but no one owns the whole thing. It's been kept alive by just saying "yes" to everyone's ideas—it would be WAY easier if one faculty member or administrator (ie a Tom Silman or Dave Newman kind of guy) was the champion of the sensors/just took on the sensors. Mark just sends open ended emails to everyone…

*** To the next team doing a similar project, I would recommend an internal owner who puts all the sensor/instrumentation stuff together and own the effort versus just getting a lot of input from several parties

*** Concerned that we may be overlooking something because there is no single owner to really dig on it…

Structured Interview: Mike Lochman (11.30.2010, 10:09-10:29am)

*note—believes Gary will know more…

1. **What is your role on the DLC project?**
   PM for the Electrical Contractor (Staff Electric)

2. **What was your role in the instrumentation of the DLC building project?**
   For Mike, would be the structural sensors

   Primary role from the instrumentation side of things, gathering information related to the actual installation of the devices

   At the time, probably less concerned about the function of them, more understanding how to install and learning the expectations of Staff on install and cabling

3. **Did you have any input into the type of sensors/instruments that were selected?**
   No

4. **How was the install of the instruments scheduled from your end?**
   Really, for us, it was more of a coordination with the University/Professor as to anticipated delivery dates so we'd understand when the product would be on site

   And coordinate with Opus (the GC) to understand where the window of opportunity would lie so can install the sensors prior to fireproofing

5. **How did you manage the instrumentation?**
   For me, more delegating to my field Superintendent (Gary) to coordinate and implement once we had the broad-brush parameters laid out

6. **How did you estimate the cost of the installation activities? Were the labor costs separated out in this estimate?**
   We read the installation instructions and basically collaborated with Gary so we could estimate how long we felt it would take to attach each sensor to the column, and then we looked at the cabling almost like it was a data drop because they're similar low-voltage, plenum rated cable, so we really just viewed the cabling as a voice-data drop (used as our benchmark)

   Labor costs are typically always separated out—our estimates are a breakdown of the necessary materials and then the labor component attached to the bill of material

   Built a simple estimate based off of # sensors, the average length of cable from the sensor to the data closet, multiplied distance x quantity to determine amount of cable, also determined an average time to install each sensor and multiply those out to get total # of hours and total # of material dollars… this was the basis for the estimate

Contract already establishes an hourly rate we can bill and a fee we can apply as a mark up

7. **What was the impact of these activities on the schedule?**
   Minimal impact—install to date occurred at time of relatively low activity on the site for us, so it wasn't a problem

   The bulk of the labor will be the cabling and the termination of the cable at the device which hasn't happened yet, but it shouldn't have an overall negative impact on schedule

8. **Were there any special training or shop drawings required?**
   Not special, no

   Shop drawings were required—needed a shop drawing of the device to tell us what the cabling requirements were (which is normal)

9. **Were there any difficulties in the install of the instruments? If so, what was it? Is there something that could have alleviated this issue?**
   Probably did find that they were pretty delicate

   Probably a little more precise than we are used to… Gary would have a better idea on any issues

10. **If you were to do another "living learning center" project which involved extensive instrumentation, what other information would you hope to have before starting?**
    To be honest, to this point, we still don't know how the information is going to be gathered and stored for MU's use…. so in a perfect world we'd have a better understanding of the expectations for the end result

    The more knowledge we could have about the end gate, or what the final result is intended to be, we can better serve our customer

    Since we don't know what the end expectation/result is supposed to be, we can't provide any suggestions, or economy like we normally do with a more traditional installations

11. **Is there any information you would have liked earlier in the construction process in regards to the instrumentation?**
    See #10

Structured Interview: Matt Bratzke (12.7.2010, 10:52-11:35am)

1. **What is your role on the DLC project?**

    Senior Project Manager for the Opus Development Corp

    Main role: to manage the construction team and the design on the project, to make sure we're meeting MU's needs, and maintaining the budget and schedule, as well as prepare the pay applications to MU – I have a team underneath me [consisting of Ben (day-to-day contracts and change orders, and direct owner purchase process/paperwork) and Chris Cromos (field engineer—his time is a little limited right now—his roles is to answer questions in the field and be a liaison between Dan Nash and the office, or Dan and the architects—gives an engineering prospective), and co-ops]—Matt also helps Ben with some of his tasks when Ben is overloaded

    Matt also involved in the MU items, "oddities" really, which are coordination issues…. (coordinating PV panels for the roof, pricing and coordination for the anemometers for the roof with faculty, coordination with MU to do the grand opening…etc)

    Do a lot of work with the city: permitting, code interpretations, etc

2. **What was your role in the instrumentation of the DLC building project?**
    This is another one of those MU related items that aren't really a typical building component—worked with Chris Foley a lot—to understand placement of sensors, make sure there was a drawing of sensor placement, minor training required which had to coordinate with Staff and Foley to make sure they knew how to install properly…

3. **Did you have any input into the type of sensors/instruments that were selected?**
    No

4. **How was the install of the instruments scheduled from your end?**
    Mainly focusing on strain gauges (and pressure plates kind of too, but not really)

    Pretty straight forward really because we didn't have too much to work around, had it come later in the project this would have been a huge challenge

    The whole goal was to get the sensors installed before the fireproofing b/c then we can just spray over them—if they had come later you'd have to cut the fireproofing where you wanted sensors, weld the sensors to the steel, and then hand-patch fireproofing in those areas (which wouldn't match the other fireproofing, and since we have a lot of exposed areas, it would look weird)

    Pressure plates all had to do was work with Crovetti as to where he wanted them, Crovetti was there during placement, and just poured concrete over them for the footing sensors, and Crovetti also helped for placement near wall that was backfilled.

5. **How did you manage the instrumentation?**
Honestly, we just had to make sure they stayed on schedule ahead of fireproofing; so we just gave Staff Electric some timing guidelines to ensure this happened

6. **How did you estimate the cost of the installation activities? Were the labor costs separated out in this estimate?**
Didn't really have costs from the Opus side for structural sensors
    - from the Staff prospective, asked for a budget of what they thought it would take to install all 123 (#?) sensors, and then added it as an allowance in their subcontract (note: they actually came pretty close to this number, a little under)

    For the anemometers, we will have some costs once we figure out who is best to install these towers (don't know who from the union really does/claims this)

7. **What was the impact of these activities on the schedule?**
Really wasn't one b/c we implemented them early enough (strain gauge)

    For the anemometers, there isn't really a schedule impact, because we're still moving forward—they can really go on at any time… the goal there would have been to beat the roof if we had had that opportunity (didn't know about these before we started roof install)

8. **Were there any special training or shop drawings required?**
Yes for Staff—Foley created drawing for Staff to locate sensors, also coordinated the training

9. **Were there any difficulties in the install of the instruments? If so, what was it? Is there something that could have alleviated this issue?**
I don't think there were any difficulties at all, it was pretty straightforward stuff… (strain gauges)

    Anemometers are going to be a little more difficult b/c the roof is on—we'll have to do more flashing (roofing component which is overlapping to ensure water tightness) and re-flashing (areas where it was already done—so have to take things off and then re-do them)
    - Note: haven't done these yet
    - If had known in advance, could have prepared for it and probably saved money b/c now the roofer will have to come back to the site (want to minimize the mobilizations!)

10. **If you were to do another "living learning center" project which involved extensive instrumentation, what other information would you hope to have before starting?**
It would be nice to site down the with Faculty members or the person in charge at the university to discuss everything they want to do, all the ideas they have, the different

sensors/instruments want to install, so we can figure out how to best do this at a reasonable cost

11. Is there any information you would have liked earlier in the construction process in regards to the instrumentation?

Since there really isn't that much in regards to sensors….

Would have been nice to know about the anemometers earlier…

- Would be nice to know earlier so we can do more architectural design (ie not having 3 huge anemometer towers—perhaps we could have done something to make them blend in more if we had known sooner—the way we've done it kind of makes it look like an afterthought, which it is)

It would have been nice to have all the Kiosk/Johnson Controls information up front so we could clarify what Staff/Grunau needs to do… at this point it hasn't really started hurting us, but it would be helpful

- Staff/Grunau doesn't really know what the vision is for this thing; so they've made some wiring assumptions at this point…. So their budget could be either overstated or understated depending on the end product we actually get

***__Other conversational notes:__**

Also noted that U of Col-Boulder has instrumentation, but isn't really using it—talked to people who toured it and said no one was really taking data from a lot of the stuff…

To Matt's understanding—we're looking at the building as a whole (in reference to energy usage, steam, water) versus at a specific VAV box for example (or an air handling unit, which is a big energy hog—there are pumps, lights, and other components that also use energy)

Trying to collect as many data points as you can to get really good understanding of our environmental impact

- why monitoring meters for the building (steam, water, gas (won't use much of this), etc—anything that has a meter now can be monitored for its usage

Wouldn't it be nice to overlay the weather for the day and the energy being used in the building

Or the time of year— so in summer have to irrigate the lawn but students aren't around, so could see if water usage goes down

- looking for correlations!

What Foley is looking for: correlating wind load on building to structural forces on the footings

Addenda to Bratzke:

Tuesday, February 08, 2011 at 1:43 PM, via email:

There really weren't any costs associated with the pressure plates. I think Crovetti set them where he wanted them prior to pouring concrete or backfilling.

Friday, April 1, 2011 at 6:36am, via email:

Currently the PV panels do not count toward LEED because they do not provide enough electricity as a percentage of the building usage to qualify. We are looking into possible ways that these PV panels might qualify for LEED innovation points.

The mixing laboratory on the lower level is to be used by the Civil department for mixing concrete, asphalt, and testing aggregates (i.e. sieve tests, etc.). The room is designed to capture the dust that will be present during the mixing process and also has concrete floors and block walls so the room can be completely washed down. The lab cabinets are stainless steel and the counter tops are made of concrete.

Structured Interview: Chris Foley, responded over email 12.8.2010

Hey Meredith,

First of all, I apologize for the long, long delay in responding. There are a couple of reasons for this and the first is the easiest…. I just now had some time to devote thought to answering the questions.

The second is a little more complicated and stems from the fact that I have spent nearly 6 years formulating discovery learning and research ideas for the DLC and its CEEN/EMST laboratory. I want these ideas to be the source of MS and PhD student research theses in structural engineering and structural mechanics education. There is a significant level of intellectual capital that needs to be spent in setting up, archiving, and using the instrumentation and data. I am currently seeking research funding to complete the instrumentation effort, support graduate students in that effort, and foster use of data in education at MU and nationwide through the National Science Foundation and the National Earthquake Engineering Simulation (NEES) Center (www.nees.org).

This activity has been planned over 5-6 years and now that building has been built, the next phase (implementation) is ready to go. Establishing the reasons for the instrumentation, the type and location of sensors, the use of the data acquired in classes at MU and universities world-wide, the use of data for potential research, etc…, is a significant endeavor and is loaded with intellectual merit. Gathering data is really, really easy - sensors today are like Kleenex. Understanding how to use the data (even if it is just in structural engineering) is even more difficult. Understanding how to use the data in engineering education is even more difficult. Making sure that the data can be used to further education in the nation (not just at MU) is even more difficult. This layering of difficulty makes instrumentation of buildings and using data a significant intellectual challenge. I don't want this challenge to be diluted through my response to a survey and I don't want this process to appear easier than it is.

I understand and sympathize with your need to generate a thesis and I realize that your thesis will likely go much wider than structural engineering. I'll do my best to give you answers that are very general in relation to the structural engineering instrumentation and data use. Hopefully, it will get you started in your information gathering.

CF

1. What is your role at Marquette?

Professor of Civil Engineering. Teach courses in structural engineering analysis and design.

2. What was your role in the instrumentation of the DLC building project?

I originated the concept for instrumenting the DLC and subsequent use of the "building" as a teaching tool for student education as member of the originating planning committee for new engineering building. I have been making presentations generating ideas for instrumentation to the College National Advisory Council, University Advancement, and other university bodies for the past 5 years.

3. Which sensor(s)/instrument(s) did you select?

Weldable strain gauges were selected to monitor strain at 100+ locations throughout the structural system in the DLC. An array of three weather stations (wind anemometer, weather vane, precipitation, etc…) on the roof of the DLC will help to correlate wind speed, wind direction, and study wind turbulence with behavior measured in the building structural system(s).

4. How did you determine which sensor(s)/instrument(s) were correct for this application?

25 years learning about and performing structural engineering analysis, design, teaching, and research provided me with the knowledge that wind and strain sensors would provide information that I would need to correlate with structural analysis and wind engineering theory. We also have BIM models that can be used to generate structural analysis models for students to correlate analysis results with actual physical measurements. We also wanted to have instruments that would give data that could be used in statics classes, mechanics of materials classes, structural analysis classes, steel design classes, etc. Accelerometers and their installation remain to be evaluated, but are on the horizon. These allow us to look at vibration sensitivity of floor systems within the DLC.

5. What can this sensor/instrument measure?

There is a ton of information related to the fundamentals of strain gages. Vishay Micromeasurements (www.vishay.com) is one company with a lot of information on how strain gages work. National Instruments (www.ni.com) is another company that provides information on how the traditional Wheatstone bridge circuit is used to measure strain through electrical resistance changes. You can check out the MS theses (available through the library) of Carl Schneeman and Andrew Smith to see how strain gages work, how they can be calibrated, how they are used, and how data acquisition software is written to measure strain using these instruments.

With regard to the anemometer…. How they work is usually buried in proprietary information. However the fundamental principles of how wind speed and wind direction are translated from electrical signal to usable data as well as their calibration can be found in manufacturer literature. One source for this is Campbell Scientific (www.campbellsci.com). You can also see how an anemometer can be calibrated in the MS thesis of Andrew Smith.

6. What are we intended to measure?

Strain (bending and axial) is to be measured and wind speed/direction are to be measured. Strain with strain gages (full, half-bridge completions) and wind speed/direction with anemometer/vane. What we are measuring with regard to strain depends upon what we have the gages mounted on and where they are mounted on that component. The plan for the gage layout is available and you can review that plan to see what we are measuring and where.

7. How should the information screen look on the MetaSys readings?

- **Are there other presentation / data manipulation software that will be required to best utilize / present the data?**

I don't know what a "MetaSys" reading is. I have not been involved in any meetings related to instrumentation, data use, data display, etc… (a bit troubling to be honest). At this point, any data acquisition hardware/software package can generate data for display on a variety of sources (e.g. monitors). I am in the process of developing ideas and the NSF proposal discussed earlier to utilize the NEES Center (http://nees.org/) and its NEEShub data repository system to provide data from the DLC to all university students nation/worldwide. Their data requirements and archival structures are strict and they have yet to be studied within the context of the DLC data usage and dissemination.

8. How often should readings be taken/updated?

- **Are there specific environmental conditions (wind / rain / snow / locusts) that are of particular interest?**

Data acquisition rates are dependent upon the natural frequency of vibration of targeted modes in the structural system. For example, the rate for lateral displacement of the building might be different than the rate for the vertical floor vibration due to occupancy. Wind is the specific environmental condition that we would be looking at and correlating this to what we see in the building's response. Wind data acquisition rates depend upon the anemometer and we have used 4 Hz in the past. Typical strain rates of acquisition have been on the order of 20 Hz. The sampling rates are determined using a theory proposed by Nyquist developed to prevent data aliasing.

9. How will the data be used?

- **Is there any data "Cleansing" that is expected?**

See the answers to 4 and 7(a) above. In data acquisition systems (DAQ systems) we often filter data to get rid of noise. Once noise is removed, cleansing per se, is not going to be done. Filtering will most likely be done, but this can be done in a post-processing state or at the time the data is acquired. I usually like to do it in a post-processing mode.

10. Why will this data beneficial to the college of engineering program?

I don't have enough time to outline all the benefits that can be generating using this data. There are benefits to not only MU, but all civil/structural engineering programs around the world. The data will be used to facilitate student understanding that what we do in engineering is create models of physical behavior. The models we use can be validated using the data coming out from the DLC. Students can then learn to develop and refine models to better predict the behavior seen through measurements.

11. How was the location of the sensoring equipment chosen?

The structural system for the DLC is unique and the locations of instrumentation (i.e. strain gages) were chosen to maximize information related to the lateral load resisting response of the system, the gravity load resisting response of the system, and the load transfer mechanisms within the building. The locations were also chosen to generate information suitable for use in all CEEN courses that incorporate structures/structural-mechanics disciplines of engineering.

12. How much time was spent in analyzing sensor/instrument options for this application?

Decades of knowledge of structural engineering and teaching of structural engineering concepts/principles made analyzing options very, very quick. The difficulty was how to get the most information for the least $$ and work things into the construction schedule.

13. Which options or products were formally evaluated?

Weldable strain gages were purchased from Vishay based upon their use in past research and teaching activity. I have used their weldable gages on research efforts in the past and they worked quite well. Anemometers have not yet been decided, but Campbell Scientific sells products from many vendors. I have used sonic anemometers from Gill in the past, but won't use them again.

14. If there was a different sensor/instrument that would have also worked for this application, why did you choose the one(s) that were installed?

Other vendors are available, but there was a history with the ones chosen. The sonic anemometer was chosen because of its resistance to icing.

15. Would you have liked more time to research options before making your selection?

More time is always better.

16. Have you seen sensors/instruments like the one(s) you chose used in applications elsewhere before? If so, where?

Virtually all health monitoring systems in infrastructure, health monitoring systems in buildings, and DAQ systems in structural engineering research use the instruments chosen. There are too many examples to list. A web search would provide TONS of examples.

17. Have you seen other instrumentation applications (at other universities / etc) that would have been of interest to have installed at the DLC?

There is no other DAQ system like that installed and planned to be used I the MU-DLC anywhere in the world. Some schools have exposed structural systems (e.g. Univ. CO Boulder), some schools have done small-scale instrumentation efforts (e.g. U of I), some schools have weather stations (e.g. Bucknell University), but none have developed a synthesized instrumentation system that can be used in teaching structural engineering/mechanics principles.

18. What prevented those from being considered?

Not applicable.

19. What instrumentation should be included in Phase II of the DLC construction

It depends upon what the second phase structure looks like. I have focused my energies on teaching applications in phase 1, but there are a ton of research-oriented questions that could be answered with further instrumentation.

Addenda to Foley:

Sunday, April 10, 2011:

-Comment on having the goal of incorporating architectural design into the weather station installation: "Architectural and engineering needs are in DIRECT CONFLICT with one another; anemometers/weather stations will always look like an afterthought, otherwise they won't measure what we want to measure"

-Comment on in a broad sense having a specific list being beneficial to the project: "in a broader sense, a commitment by the building owner to the installation of sensors and the provision of time for faculty to properly develop plans for sensor installation and use would be beneficial"

Structured Interview: Ron Kwiatkowski (12.15.2010, 8:43-9:10am, on the phone)

1. **What is your role on the DLC project?**
   From Grunau, Mechanical PM—in our company go from the origination of the job, involved with the design engineers, GMP (guaranteed max pricing), procurement of the equipment needed on the project, daily management, get involved with field labor and deliveries, really do cradle to grave… if there are any issues afterwards (warranty or issues, etc) Ron would be the contact at Grunau

2. **What was your role in the instrumentation of the DLC building project?**
   Looking at 2 different things here—TG is working with Johnson Controls directly

   We're working with JC with HVAC/Mechanical system to monitor control, and Staff electric will do the install

   In the temperature control system, an air handling system for instance, there is a coil in it, and we will have a sensor on it, where JC can monitor what temperature it's at…. You can monitor that temp, the temp of water from the chilled water plant…. There is a huge laundry list JC is monitoring on this project
   - water and air temps in the air handling systems
   - water temps on the heating systems
   - water temps on the chilled water system
   - monitoring air flows at the air handling units and at VAV boxes
   - plumbing alarms
     - basically dealing with water and air temps…
   - "control instrumentation" in HVAC/MEP systems

3. **Did you have any input into the type of sensors/instruments that were selected?**
   No, basically tell JC what want to be able to do, and JC selects the device (the control contractor actually picks the device)

4. **How was the install of the instruments scheduled from your end?**
   Basically follows the sequence of the job
   - Ron schedules JC to be out there as the equipment is installed

   All driven by Opus' general construction schedule; really dictates everything for us (ie when they put walls up, we have to be ready to do thermostats)

   Combo of GC requirements and delivery of equipment
   - When the roof top comes, we can call JC to tell them it's here and that they can start installing and wiring what they need to on the unit

5. **How did you manage the instrumentation?**
   Basically driven back in the engineering stage, when we designed the control system, so it was written into control sequence specification… nothing different than a normal job

   MU is different than normal on the job by working direct with JC
   - How the data is being displayed (Kiosk) to the students for their use and observations
   - Otherwise we're collecting the same kind of data as in other buildings, the only different thing is how it's being displayed
   - On the mechanical end, we're following the same basic thing we did at the law school/similar…

6. **How did you estimate the cost of the installation activities? Were the labor costs separated out in this estimate?**
   JC did that direct with Staff Electric and Marquette—install of the temperature control system was not a part of our cost

   JC is a sub of Grunau, and Staff is a sub of JC to do the install (this is the way TG wanted to do it)

   Usually we would carry the installation, monitor the costs of it, carry the bids for it…. (different than normal)

7. **What was the impact of these activities on the schedule?**
   Isn't really one, just follows the construction sequence

   It's Grunau's job to make sure that it follows the rest of the mechanical installation schedule

   If there was any kind of impact, it will be getting the control contractor (JC) to deliver their equipment to the jobsite to meet the schedule
   - ie) on a VAV box there is a control valve to install the piping… so just making sure it's there on time to install the piping….

8. **Were there any special training or shop drawings required?**
   There are always shop drawings required for review

   JC will develop submittals/shop drawings and gives them to Grunau who looks at them to make sure they were what Grunau had designed, and then they are forwarded to the owner for their review. It is also sent to Opus when sent to the owner.

   Special training is at the end of the job—the whole mechanical construction team meets with the university to do a commissioning process, which is really a walkthrough of the whole system. It trains them in the operation of the mechanical systems—but this is way at the end of the job. Usually a day where you bring out all the equipment suppliers, and it takes a couple of hours each, and shows the people who will be actually operation team; really a transfer from the construction to the operation side

9. **Were there any difficulties in the install of the instruments? If so, what was it? Is there something that could have alleviated this issue?**
   I don't anticipate this, we haven't started this yet

   In the project, the only challenge I can see is the aesthetics b/c of all the exposed ceilings (there are no dropped ceilings on the project)—so we have to be careful about making our work look pleasing

   The only thing that could alleviate this issue to put a ceiling in….

10. **If you were to do another "living learning center" project which involved extensive instrumentation, what other information would you hope to have before starting?**
    Not sure there is anything there—this is more on the universities side—we're not doing anything different at this stage

    If I were Marquette or anyone involved in it, understanding what you want to see, understanding what control points want to pick up—seems to be just evolving now, and maybe that could have evolved earlier…. Really just an earlier start on identifying what you want to see as an end result

11. **Is there any information you would have liked earlier in the construction process in regards to the instrumentation?**
    See #10

Structured Interview: Ben Baenen, responded over email 12.15.2010

1. **What is your role on the DLC project?**
   I am a Project Manager on the Marquette University College of Engineering. Specifically my role is one of day to day business and scheduling of the project, including incorporating what is learned on the design process into specifications, estimating, budgets, bidding, contracting, issue tracking, cost projecting, etc. I work directly with and under Matt, the Sr. PM.

2. **What was your role in the instrumentation of the DLC building project?**
   My role in instrumenting was limited. I facilitated the installation of the ground pressure sensors by scheduling University Professors; and had very little to do with the structural sensors. The Professors specified the sensors used and oversaw the installation.

3. **Did you have any input into the type of sensors/instruments that were selected?**
   No, chosen completely by the professors.

4. **How was the install of the instruments scheduled from your end?**
   - As for scheduling, I worked specifically with Crovetti and put Dan Nash the site superintendent in contact with him. Through Dan, Crovetti was informed of specific events he requested scheduling dates on.

5. **How did you manage the instrumentation?**
   No

6. **How did you estimate the cost of the installation activities? Were the labor costs separated out in this estimate?**
   We did not include any instrumenting the estimate for the project. The sensors and equipment were purchased out of the University budget, however we did end up carrying the cost of welding the structural strain gauges on the building. We were provided a maximum price from Staff after they were shown how to install a single sensor.

7. **What was the impact of these activities on the schedule?**
   None, all activities were conducted prior to any other Critical Path items.

8. **Were there any special training or shop drawings required?**
   Staff, as the installing contractor of the strain gauges, was trained by Foley to use the specialized welder to correctly mount the sensors.

9. **Were there any difficulties in the install of the instruments? If so, what was it? Is there something that could have alleviated this issue?**
   Not to my knowledge, we probably could have had a more efficient and controlled process if the locations were specified prior to the structure being erected.

10. **If you were to do another "living learning center" project which involved extensive instrumentation, what other information would you hope to have before starting?**
    The need for a specific list of items the facility should incorporate so a budget and instrumenting could be managed with the building design more thoroughly.

11. **Is there any information you would have liked earlier in the construction process in regards to the instrumentation?**
    In addition to the structural and civil sensors, MU is working with JCI to provide a series of other 'sensors' to measure any number of items. This work is being conducted separately, but in conjunction with the building construction. These sensors have the ability to be added at any point.

Structured Interview: Erik Hendrickson (2.25.2011, 11:45am-12:24pm)

1. What is your role at Marquette/in the DLC building project (ie: how are you involved in the project)?

- PM for the technology portion of the building; the security systems, access control, cameras, the data network, etc
- Works for MU's IT Services (ITS)

a) Were you directly involved with any of the instrumentation/sensors on the project?

- Strain gauges were all put in prior to me being involved
- As far as the weather stations—working on picking out the instruments with the faculty's input
    - They want sonic anemometers (versus 3-cup)
    - Looking to purchase 3 anemometers
    - Also getting temperature sensors AND a solar radiation sensor AND precipitation measure that would go on the tower...

Amended 3.26.2011:

- Actively working with the Stakeholders and Electricians to determine the proper cabling for sensors

2. How does ITS and the Office of the University Architect work together on this project? (ie: does ITS act as a sub-contractor? as a consultant? other?)

- Almost like a sub-contractor/consultant → OUA utilizes the specific knowledge of technology within ITS to manage the technology portions of the project

Amended 3.26.2011:

- I work closely with OUA to determine the scope of the work that is required and OUA has a very large part in defining the scope and requirements. Once the scope is defined ITS works to determine the best methods to meet the requirements. I will then work to put together a budget and system design for review with OUA. If the proposed budget exceeds what is feasible it becomes an iterative process to manage the scope to get back within budget

3. Asked about who would do what ITS does if there wasn't an internal technology services department—he wasn't sure; said possibly the owner or the GC—could also possibly contract with a technology specialist… not sure

Amended 3.26.2011: Knows that Johnson Controls has a technology consulting wing but isn't sure exactly what they do. The value added by having ITS on board is that Erik is able to function as a single point of contract between all of the technology contractors and work to bridge the gap between Technology and Architecture/Construction

4. What are the considerations that impact ITS in regards to instrumenting a building?

- How they would impact MU's data network—either implemented into the network or being separate
- How the data is captured—if it needs a separate server, if it's captured in MetaSys, if it needs storage space…
- What hardware and servers might be needed
- If it has a website component to it, how that would work (separate server, run's in MU's domain, etc)

Amended 3.26.2011:

- The requirements of the facility
- How the kiosk itself will be used and what sort of information will be displayed

5. What considerations need to be included for maintenance, software and hardware upgrades, and additions to the instruments/sensors being measured in the DLC from an ITS perspective?

- A lot of this is going to end up being owned by the college- so the actual maintenance of the sensors themselves doesn't really concern ITS
- 2 main servers in the DLC: The Kiosks has a server, MetaSys has a server—things like this ITS does regular patching/upgrades to ensure it's up to date and working right, and secure
- ITS maintains the stuff out of the data center (**<u>servers</u>**)

6. Where there any challenges in figuring out how to implement these devices in the DLC? If so, what were they?

- **<u>SCOPE DEFINITION</u>**!!! There is a lot of different professors involved and all want to do different things, but it's hard to pin down what they actually need and want
- **<u>Figuring out the Requirements</u>**! Ie) need an anemometer… what does it have to do? What is it measuring? Tolerances? What data are we gathering? What do you want to do with the data collected? How should the data be displayed on the Kiosk so that anyone could understand it?
- **<u>Possibly more difficulties/challenges to come</u>**; still working through this process…

7. What is the benefit to Marquette's College of Engineering, and the University as a whole, by installing these Kiosks in the DLC?

- This is just something ITS has been asked to help with, and it's their job to work with the technology aspects… but for the University as a whole, it helps the students, it's really cool to see how things work even if you don't understand all the math behind it…

(*Some of the below questions may be more appropriate for JCI, but thought I'd get ITS's take on them if possible. If they do not pertain to you, please answer "n/a")

8. What is a Kiosk, and what is its purpose in the DLC?

- A physical touch-screen display in the building → this is the Kiosk
- There is an online component so someone could go online and view the static info in the building (LEED points), as well as live data (energy, water consumption, strain, weather impact, etc), from the DLC

Amended 3.26.2011:

- Will have an online component so the information can be viewed online
- A kiosk is really a way to translate raw data into more usable information that can be understood by a layperson

9. How do the Kiosks work? (equipment needed to run them, how they are wired, how the sensors/instruments of the DLC are connected, other relevant info, etc)

- The stuff MetaSys collects (HVAC/etc) goes into MetaSys
- Anything that's not in MetaSys (ie- strain gauge) will go into something like a National Instrument black box (DAQ) which will then communicate to the Kiosk through some industry standard communication protocol which lets these 2 systems "talk" with each other over the (Internet Protocol) IP network

10. What information will the Kiosks display, and what will the display look like?

- n/a at present. It's safe to say will display static info on the building and "green features" and live data, the actual design/display and the information that will be displayed is in progress

11. How is the Kiosk installation being managed?

- ITS/OUA will pick the size of the screen
- ITS will coordinate the order and delivery
- ITS will work with Staff to ensure there is power and data for it
- ITS will work with OPUS to make sure it can physically be supported, it's to code (ADA)
- JCI will be doing the software programming

12. How was the cost of the Kiosk installation determined?

- Had to look at all the components we are using in the field (**component cost**), how much the JCI **screen costs**, have to consider the **cost of the application server** that will run the software for the Kiosks, and how much JCI **software development will cost**
- Note: this cost has not been entirely determined yet—because we're still defining the scope of the living laboratory system

13. Has the location of the Kiosks been selected? If so, how were the locations chosen?

- So far we're looking at only ONE kiosk—will be located on level one somewhere… TBD.
- BUT all this information can be available to be accessed on the internet

Amended 3.26.2011:

- The location was chosen by OUA/Opus A&E; it will be located on the Wisconsin Level by the elevators

14. How will the Kiosk system be maintained in the DLC?
Amended 3.26.2011:

- The college of engineering will perform the vast majority of maintenance
- ITS will maintain the servers in the datacenter

15. Where there any challenges in figuring out how to implement the Kiosk's in the DLC? If so, what were they?
Amended 3.26.2011:

- Determining the correct stakeholders to assist with requirements
- Getting the right subject matter experts on the project

16. Have these types of devices been used in other building applications? If so, where? and what do they display?
Amended 3.26.2011:

- Yes, these have been used in several applications

*****Advice/Lessons Learned:**

Make sure you have a champion for the living lab system from the beginning!!

Amended 3.26.2011:

- Everything is designed by committee (aka- there are a lot of people involved)
- Having one person would help solve disputes among different stakeholders/committee members; would make executive decisions to keep things on track
- think because such a broad system, there will always be a lot of people involved, but having a point person would help guide all the others, be able to find answers, and make decisions—they'd really be the representative
- the dean would be the sponsor, the faculty/OUA/GC/students/anyone who will be involved or benefit from the project would be considered the stakeholders, ITS's job is to figure out who all the stakeholders are and figure out what they want and then get it all done (from the technology perspective of the project) → having a point person would be having a single person for ITS to talk with who represents all of the stakeholders within the college of engineering (basically they'd represent the instrumentation/sensor efforts)

Structured Interview: Brad Bonczkiewicz (2.28.2011, 9:36am-10:16am)

1. What is your role at Marquette/in the DLC building project (ie: how are you involved in the project)?

- College Representative for all of the technology integration
- Works directly for COE as Computer Systems Manager—the director of COE's own IT for the in-house systems
- In terms of the DLC—we're the ones purchasing everything for it, and will be supporting all the technology—it's our users that will be using what we install

2. Were you directly involved with any of the instrumentation/sensors on the project?

- Not initially—Crovetti, Foley, Federle… mostly the civils that jumped on board right away and put the sensors in the right spots
- Getting involved with it now—to get the weather stuff up on the roof (Erik Hendrickson's taking a bigger role in that)
    - Erik is going to make sure the Kiosk system is there and programmed
    - The College is in charge of what goes into the system/what should be displaying on the Kiosk—the content!

3. How does ITS and the Office of the University Architect work together on this project? (ie: does ITS act as a sub-contractor? as a consultant? other?)

- The COE Dean is the customer, but it's the campus Architect who's responsible for the budget and the constructions of the building…
- The Arch has cut out a slice of the budget for ITS needs/overall technology things that will be part of the building (ie- security, networking)
- **Would say ITS acts as a partner more than a sub-contractor or a consultant, although they do serve those roles as well → really a partnership between the college, the architect(s), and ITS
- Brad considers himself as part of the college—but role is really intertwined with Erik's from ITS (Erik is the implementer, Brad is the go-to for the customer)

4. What are the considerations that impact your department in regards to instrumenting a building?

- As COE Technology Services Manager (As a representative of the COE): to understand what the faculty/staff want for instrumentation and then implement it appropriately
- from the department that I run (tech support) to make sure that it integrates with our current or new systems we are implementing—making sure we have the technology resources in the college available to support any new systems we create (knowledge of the systems, staff to help fix/run/etc)
- what's happening with MetaSys itself—ITS will be running the MetaSys server b/c there is so much of this same system already implemented across campus
- the Kiosk system—we don't know yet how to best integrate new needs, or how easy it will be to update—right now think ITS will host the server, but think we'll need to go to JCI for programming changes

5. What considerations need to be included for maintenance, software and hardware upgrades, and additions to the instruments/sensors being measured in the DLC from an technology support perspective?

- Cost (device, to have installed, to have Kiosks reprogrammed, total cost of ownership for each sensor and the sensors collectively as a whole)
- Know how to integrate them into the systems, and if it's possible to integrate them
  - The stuff that was already purchased was done before having a good technology review (didn't consult JCI)—but it's the job of our college, as engineers, to make it work…
    - For instance, strain gauges will not go directly to JCI, they will first go through a national instruments box that acquires the data through electrical signals, interprets them, and then we can write programming code to fix any issues… we haven't really gotten this far yet…

6. What is the benefit to Marquette's College of Engineering, and the University as a whole, by installing these instruments/sensors, and the Kiosks in the DLC?

- Part of it is research… the only research project that comes to mind at the moment is Dr. Borg who wants to put the really large weather stations and anemometers to see the turbulence and directions/speed/etc of the wind--- he says he has good publishable research he can do in regards to putting an urban weather station
- Monitoring maintenance (MetaSys)
- Automation—would include monitoring capacity (no people = turn down heat), etc… lights turning on and off when needed automatically…

7. What devices are JCI providing for the DLC project? How is Marquette using them, and what are their capabilities?

- The only integration Brad is aware of right now is the Roscor—A/V integration… (only specifics that he could comment on right now)
- Assuming they are doing other integration projects, so don't know the specifics
  - JCI's doing all of the actual mechanical sensoring (steam, HVAC, etc)
  - Somebody will eventually need to integrate information to the Kiosk system
  - **n/a** really

8. What is a Kiosk, and what is its purpose?

It's a computer display to educate people—we actually get LEED points for this

9. How do the Kiosks work? (equipment needed to run them, how they are wired, how the sensors/instruments of the DLC are connected, other relevant info, etc).

- All the sensors either tie into JCI's equipment or a data acquisition device… then it all gets put into MetaSys through JCI's equipment
- The kiosk system pulls all the data out of MetaSys and displays it the way we want it to

10. What information will the Kiosks display, and what will the display look like?

- Don't really know what it will look like yet—are going to work with a graphic designer to make it look pretty
- Currently in the process to figure out what we are going to display—
  - kind of looking what has already been installed and what we can learn from that
  - strain info being tied into a DAQ system—the people from National Instruments said that if we provide a floorplan, we can create strain diagram showing strain near real time with a color scheme (ie—the darker red a gauge is, the more strain it is feeling)—we also want to tie this into the weather stations on the roof…
    - another application is having students going into a room and see how it affects the strain on a beam

11. What considerations need to be included for maintenance of the kiosks, any changes in the presentation of the material, different ways users can interact with the system, etc?

- right now, we're going to have the basics (ie what we have from the strain gauges) and a few other little bells and whistles
- would like to build it into a more animated display
  - dashboard dials…
  - graphs for over time…
- people have already asked if we can update every week to show what research has been done—this takes a lot of work!! Hoping to display more static content (which could also be live static)—static is something that we don't have to update constantly; it **updates on its own**

12. How is the Kiosk installation being managed?

- The architects are designing and locating the actual placement of the monitor
- JCI is giving us the actual hardware for it….
- It's going to be built into the same wall as the elevator so it fits right into the wall…
- Brad/Erik working on specs (how large it is) and asking Staff to provide enough power… (it's really just like a TV and a computer)

13. How was the cost of the Kiosk installation determined?

- Not sure it has been… this is Erik's budget item
- Guessing ITS just called JCI to get cost for budget item and then tell Opus…

14. Have the locations of the Kiosks been selected? If so, how were the locations chosen?

- Yes—1 on the same wall as the elevator

15. How will the Kiosk system be maintained in the DLC?

- Not sure at present—any changes that happen to the programming is JCI; obviously if it breaks down JCI needs to fix

16. Where there any challenges in figuring out how to implement the Kiosk's or any other data or sensor things in the DLC? If so, what were they?

- Haven't really gotten to the Kiosk things yet… still managing sensors
- Think this project could have been managed bottom up or top down
  - We're doing bottom up; pick sensors and then figure out how to use it
  - If we did top down, we'd figure out what we want to measure and then choose the instruments

Structured Interview: Scott Wrenn, responded over email 3.1.2011

1. What is your role in the DLC building project (ie: how are you involved in the project)?

We (Johnson Controls) are the design build contractor for the Building Automation System/Temperature Controls.

a) Were you directly involved with any of the instrumentation/sensors being installed in the project?

We will potentially be involved in how the information is displayed.

2. What kind of contractor is JCI to Marquette-- a control contractor? energy contractor? (*From talking to the mechanical contractor's PM, I know they're installing JCI devices, but I wasn't sure what to call JCI without using your specific name...)

We actually have done both for MU. We helped with an Energy Retrofit that was paid for out of energy savings. We are also the Temperature Controls Contractor on campus.

3. What devices are JCI providing for the DLC project? How is Marquette using them, and what are their capabilities?

We are providing the temperature sensors, dampers, control valves and other devices necessary for the temperature control system. We will also be integrating into various other systems in the building (ie lighting control system). In addition, we are providing the main air handling systems for heating,, cooling, and ventilating the building.

4. What other devices could be used in the DLC that we are not using (ie, what are they, and what do they do)?

(no answer provided)

5. How is a building's system developed by JCI?

The systems that we provide are dependent on the mechanical systems that are laid out by the design engineer. In this case the Grunau Company is the designer of the mechanical system. After we receive the designed mechanical system, we design and engineer the temperature control system to control as the designer intended.

6. How is the system then maintained?

Systems are typically reviewed annually for operation compared to design. Sometimes, depending on criticality, they are reviewed more often.

7. What considerations need to be included for maintenance, software and hardware upgrades, any additions to the instruments/sensors being measured, etc, in the DLC?

Temperature control systems today are technology (IT) driven. Much like you would upgrade IT systems with software upgrades, you would do the same for today’s temperature controls systems. The hardware for the temperature control system is usually designed to last longer than the typical IT system. We still have systems working today that were installed over 20 years ago.

8. Was the DLC project set up about the same as a normal project, or was the system done differently for any reason?

Projects typically fall into 2 categories. Design build and fully designed. DLC is a design build project.

9. What is a Kiosk, and what is its purpose?

A kiosk is a "information station". It is designed to provide relevant information to users. In the case of the DLC, it will provide information on the building systems and their performance.

10. How do the Kiosks work? (equipment needed to run them, how they are wired, how the sensors/instruments of the DLC are connected, other relevant info, etc).

In the case of DLC, the kiosk will be server based and have multiple locations for display of information.

11. What information will the Kiosks display and what will the display look like?

The current plan is for the kiosk to display the building system (HVAC) and their performance, building structure sensors and the effects of the environment (wind) on the structure. In addition, there has been discussion on displaying information from the individual labs in the DLC. The display will most likely be a touch screen for users to navigate through.

12. What considerations need to be included for maintenance of the kiosks, any changes in the presentation of the material, different ways users can interact with the system, etc?

The kiosk would be maintained much like the other IT equipment that is on campus. Because the kiosk gathers its information from other systems, if those systems are modified the kiosk would also need to be revised.

13. How is the Kiosk installation being managed?

The kiosk resides on the MU IT infrastructure and will be wired by the data contractor.

14. How was the cost of the Kiosk installation determined?

The cost of the kiosk has not been determined yet.

15. Have the locations of the Kiosks been selected? If so, how were the locations chosen?

No

16. How will the Kiosk system be maintained in the DLC?

This has not been determined, however, I assume that MU IT will maintain.

17. Where there any challenges in figuring out how to implement the Kiosk's in the DLC? If so, what were they?

Still in process. **The challenge is determining what information to display**.

18. Have these types of devices been used in other building applications? If so, where? and what do they display?

Yes, they are most commonly used in LEED certified buildings for display of energy consumption/production information.

19. What is the benefit to Marquette's College of Engineering, and the University as a whole, by installing these Kiosks in the DLC?

It is a way of displaying the lab activities and information to visitors and prospective students.

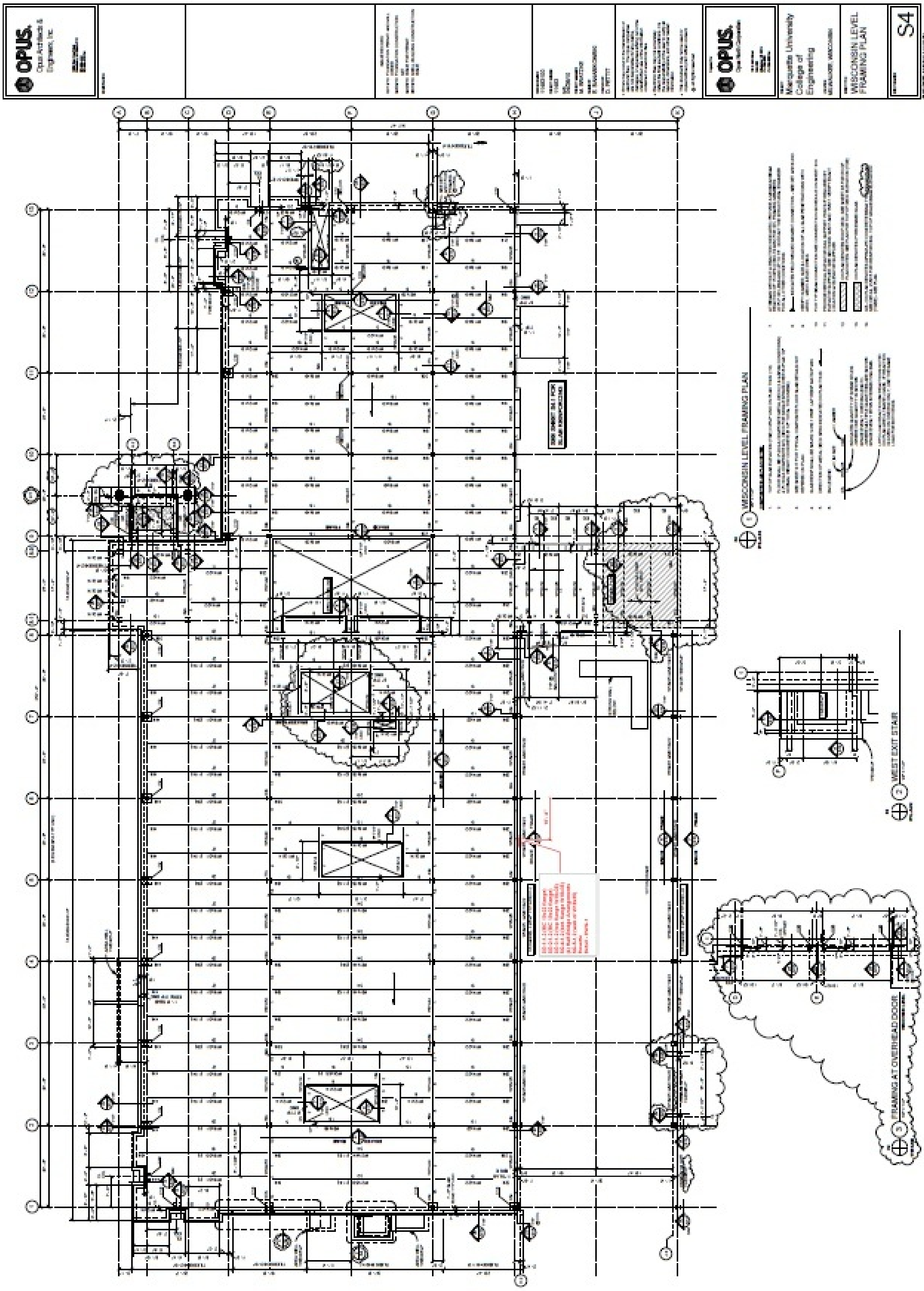
20. How is Metasys currently used on campus? How might the use be improved to enhance cost savings, etc.?

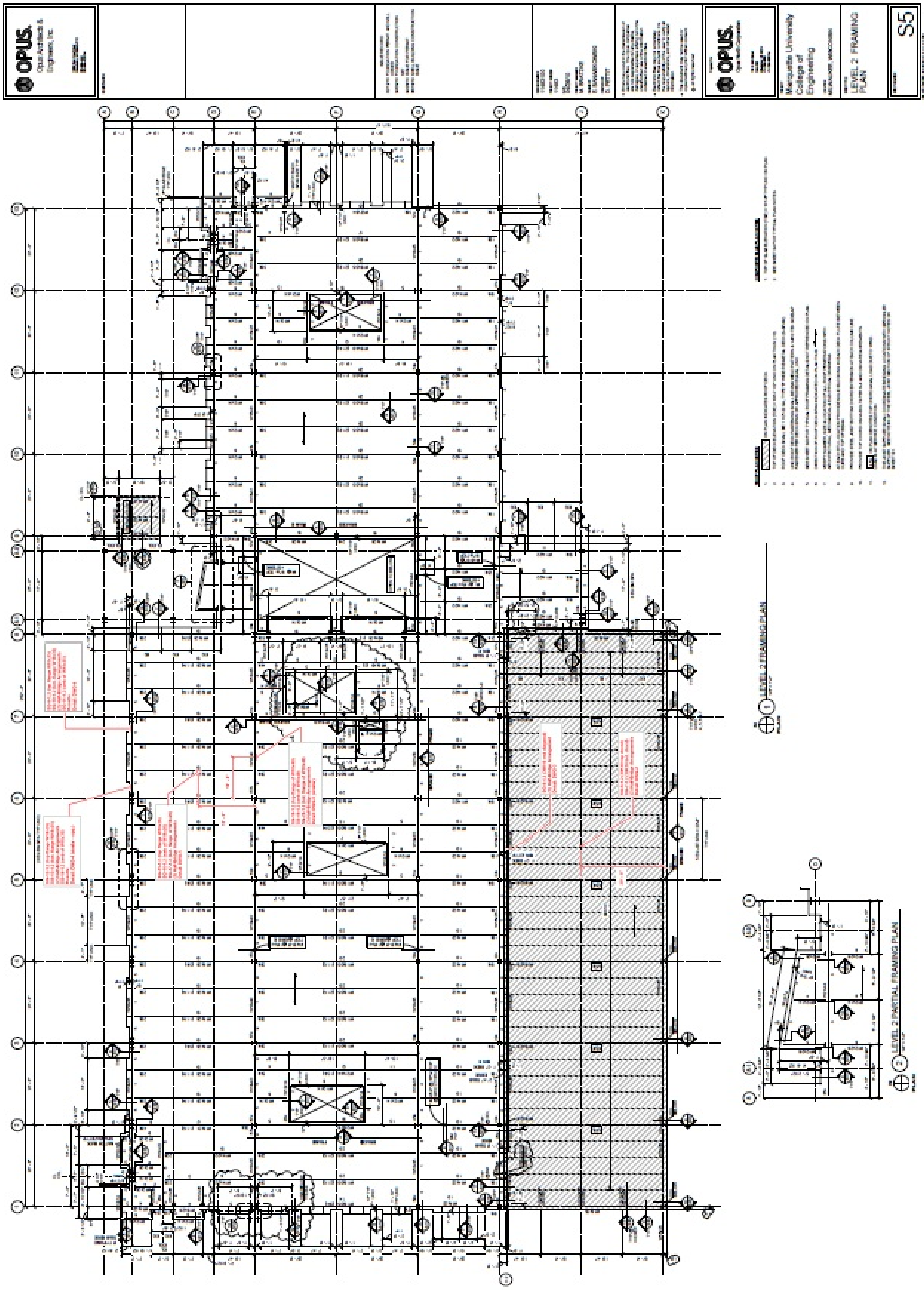
Metasys is currently used for controlling the mechanical equipment on campus. This includes air handling units as well as the central chilled water plant. If there is a failure, or if systems are operating outside of certain parameters, alarms are issued to the Facilities department to notify them of the problem.

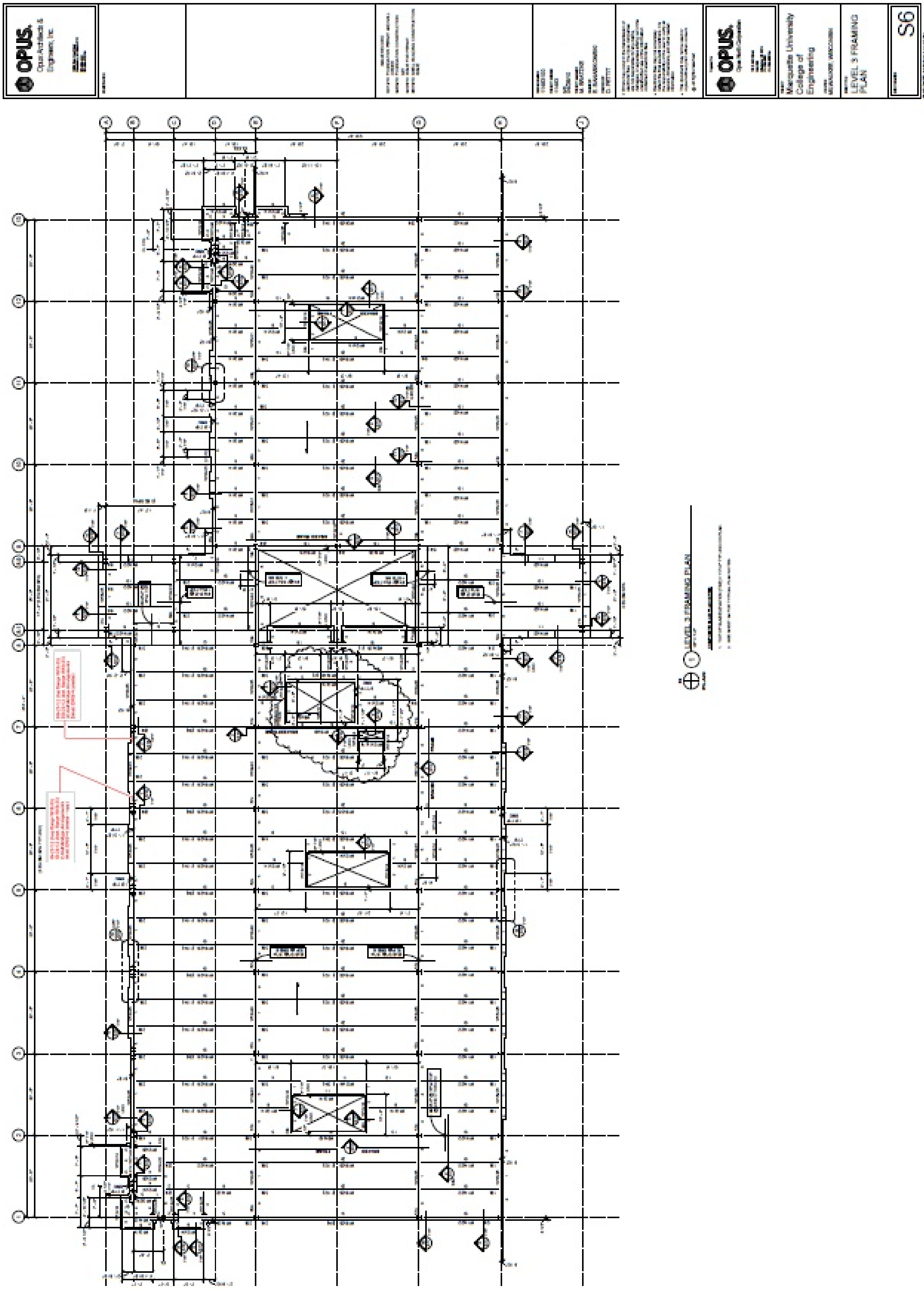
21. Are there other products like Metasys? If so, what are they?

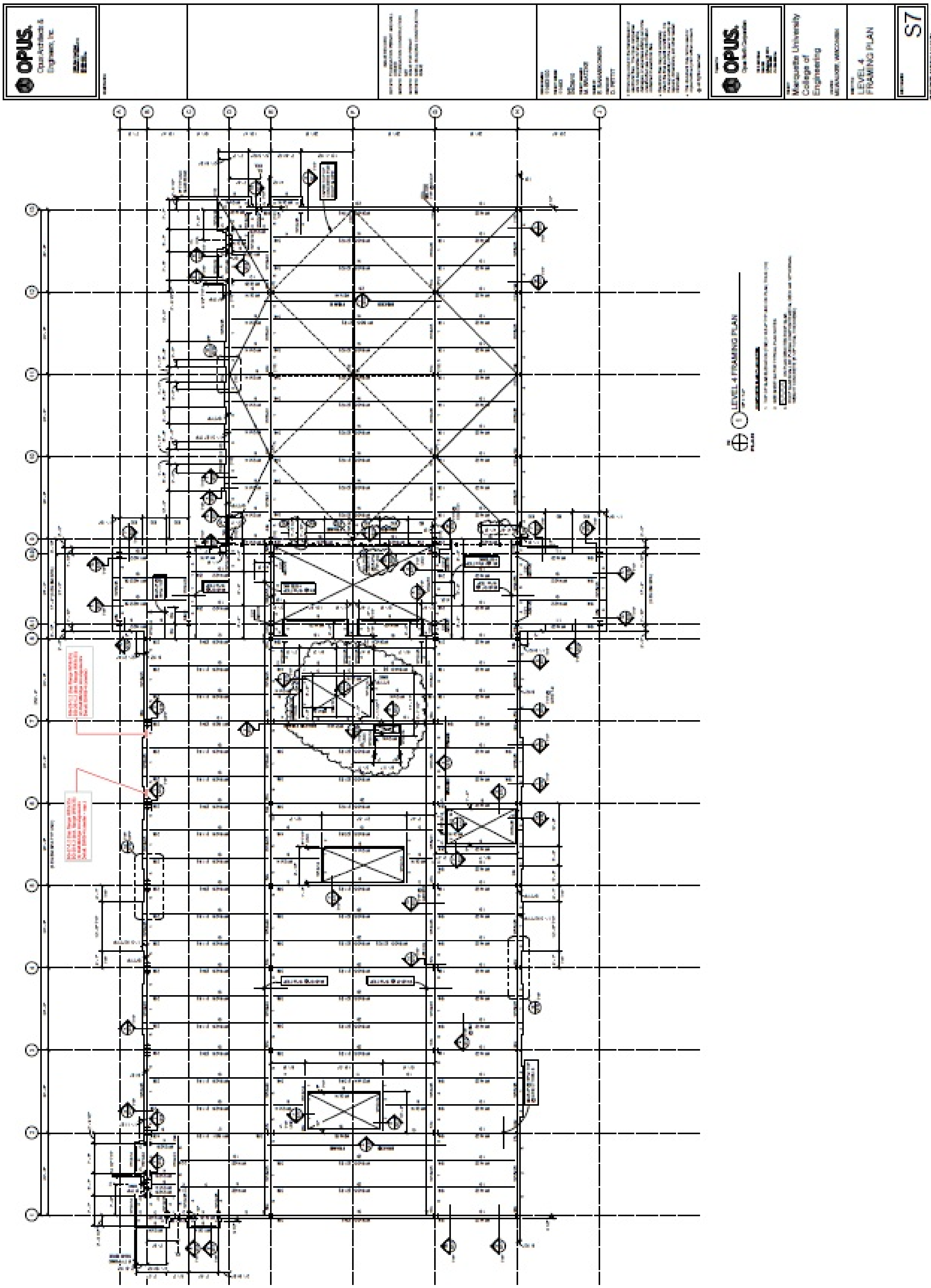
From JCI, no. However, there are others in the market.

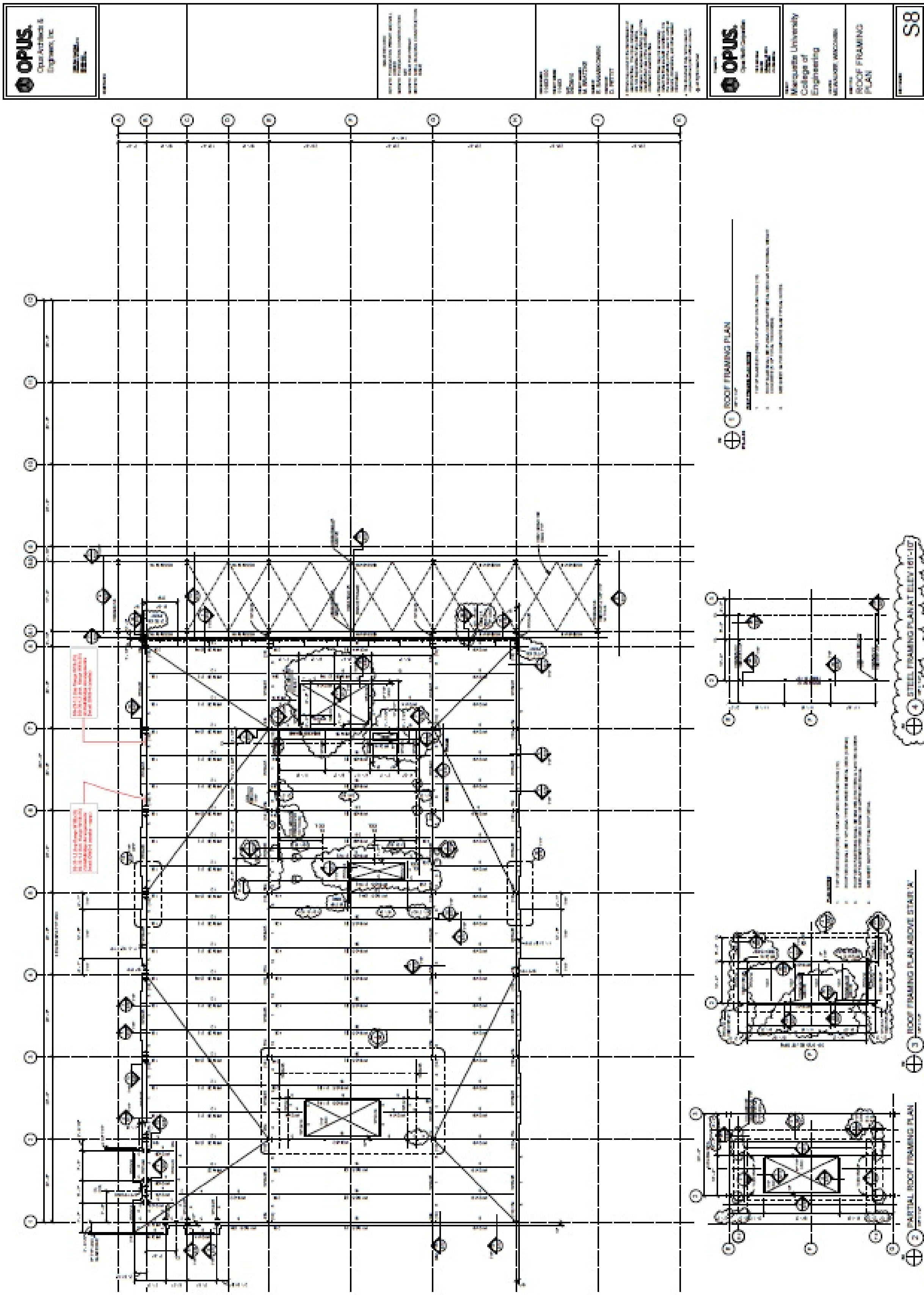
Appendix B: Strain Gauge Layout

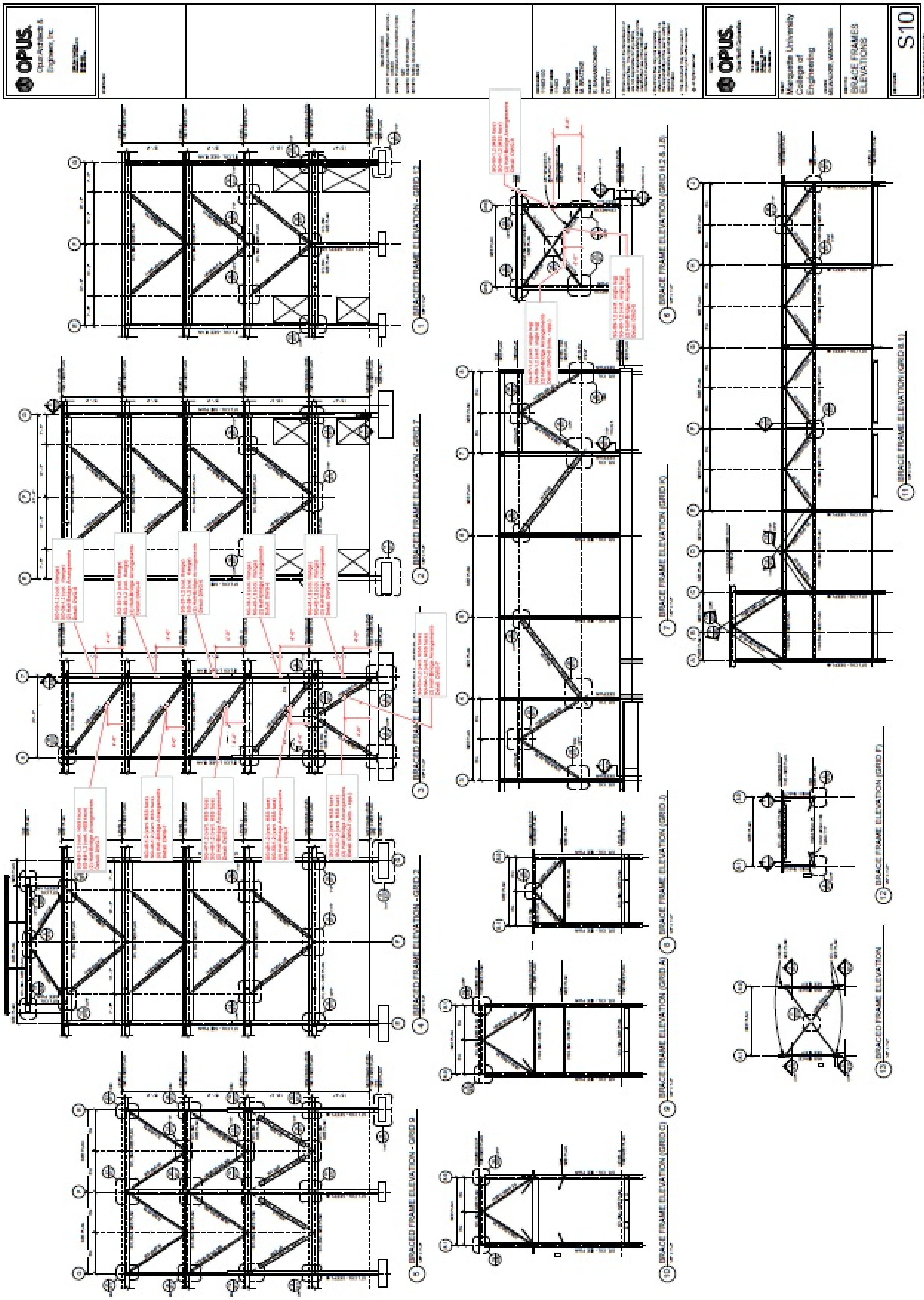

OPUS.
Opus Architects & Engineers, Inc.
OPUS.
Marquette University
College of
Engineering
WISCONSIN LEVEL
FRAMING PLAN
S4
WISCONSIN LEVEL FRAMING PLAN
WEST EXIT STAIR
FRAMING AT OVERHEAD DOOR


OPUS.
Opus Architects & Engineers, Inc.
OPUS.
Marquette University College of Engineering
LEVEL 2 FRAMING PLAN
S5
LEVEL 2 FRAMING PLAN
LEVEL 2 PARTIAL FRAMING PLAN

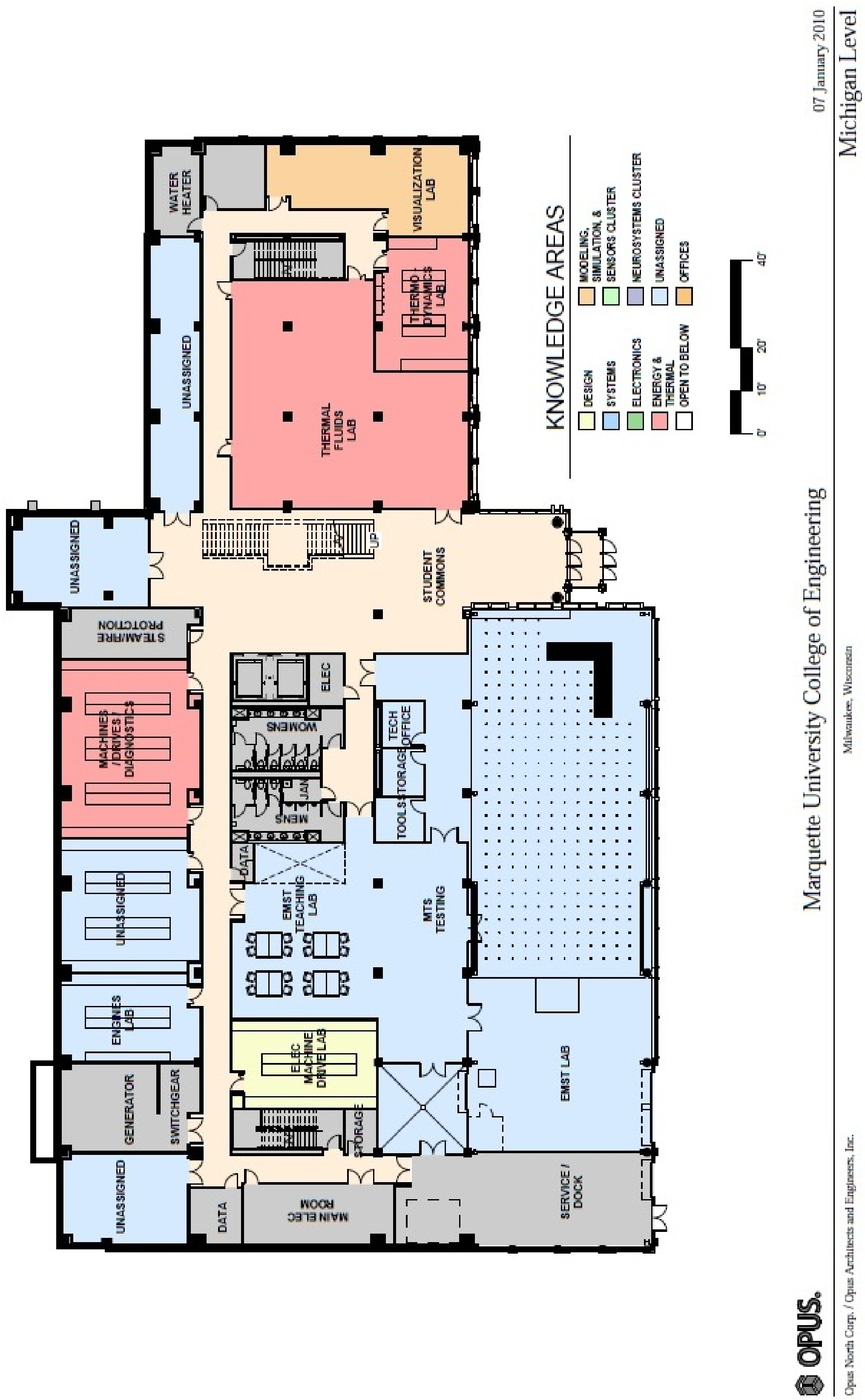

OPUS.
Opus Architects & Engineers, Inc.
Marquette University College of Engineering
LEVEL 3 FRAMING PLAN
S6

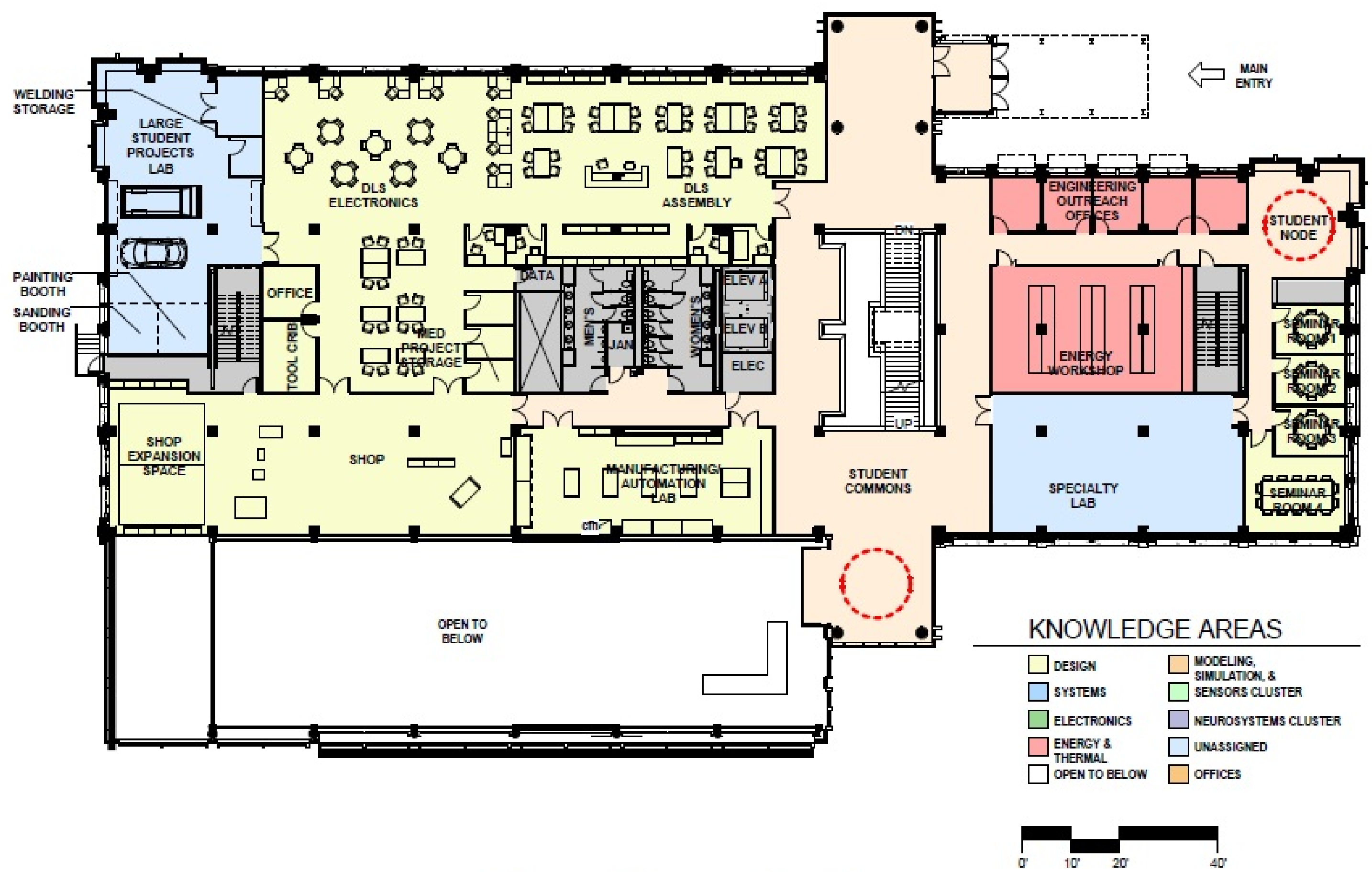

OPUS.
Marquette University College of Engineering
LEVEL 4 FRAMING PLAN
S7


OPUS.
Marquette University College of Engineering
ROOF FRAMING PLAN
S8
STEEL FRAMING PLAN AT ELEV 161'-10"
ROOF FRAMING PLAN ABOVE STAIR 'A'
PARTIAL ROOF FRAMING PLAN


OPUS
Marquette University College of Engineering
BRACE FRAMES ELEVATIONS
S10

Appendix C: Lower Level and Level One Floor Plans


Michigan Level
07 January 2010
Marquette University College of Engineering
Milwaukee, Wisconsin
OPUS.
Opus North Corp. / Opus Architects and Engineers, Inc.
KNOWLEDGE AREAS
DESIGN
SYSTEMS
ELECTRONICS
ENERGY & THERMAL
OPEN TO BELOW
MODELING, SIMULATION, & SENSORS CLUSTER
NEUROSYSTEMS CLUSTER
UNASSIGNED
OFFICES
0' 10' 20' 40'
WATER HEATER
VISUALIZATION LAB
UNASSIGNED
THERMO-DYNAMICS LAB
THERMAL FLUIDS LAB
UP
STUDENT COMMONS
UNASSIGNED
STEAM/FIRE PROTCTION
ELEC
WOMENS
MENS
JAN
TECH OFFICE
STORAGE
TOOLS
MACHINES / DRIVES / DIAGNOSTICS
DATA
EMST TEACHING LAB
MTS TESTING
UNASSIGNED
ENGINES LAB
ELEC MACHINE DRIVE LAB
GENERATOR
SWITCHGEAR
STORAGE
EMST LAB
UNASSIGNED
DATA
MAIN ELEC ROOM
SERVICE / DOCK



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Marquette University College of Engineering

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Opus North Corp. / Opus Architects and Engineers, Inc.

Milwaukee, Wisconsin

Wisconsin Level

Appendix D: Spread Footing Earth Pressure Cell Calibration Data

Geokon Earth Pressure Cell Calibration Data, Regular Spread Footing Cell

Transducer Type: 3510-2-400KPA

Transducer Number: 1012457 (G4)

Date: 5/19/2010

Tech: JAC/JPS

Piston Model Number: RC 2510

Piston Effective Area: 5.16

Ram Pressure, psi	Logger Reading	Fluke Voltage	Plate Load, lb
0	34	0.167	70
50	106	0.510	328
100	158	0.764	586
150	206	0.996	844
200	260	1.258	1,102
250	318	1.537	1,360
300	398	1.920	1,618
350	462	2.241	1,876
400	526	2.550	2,134
450	599	2.905	2,392
500	675	3.270	2,650
550	735	3.565	2,908
600	813	3.933	3,166
650	895	4.330	3,424
700	971	4.700	3,682
750	1024	5.082	3,940

Geokon Earth Pressure Cell Calibration Data, Combined Spread Footing Cell

Transducer Type:	3510-2-400KPA
Transducer Number:	1012456 (G6)
Date:	5/21/2010
Tech:	JAC
Piston Model Number:	RC 2510
Piston Effective Area:	5.16

Ram Pressure, psi	Logger Reading	Fluke Voltage	Plate Load, lb
0	86	0.418	70
50	185	0.897	328
100	258	1.255	586
150	331	1.611	844
200	413	2.004	1,102
250	491	2.385	1,360
300	575	2.791	1,618
350	661	3.210	1,876
400	738	3.582	2,134
450	828	4.016	2,392
500	904	4.383	2,650
550	989	4.790	2,908
600	1023	5.187	3,166