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MODES OF APPLICATION OF SMART STRUCTURES AND SYSTEMS IN CONSTRUCTION

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ABSTRACT
A smart structure is one that monitors itself and its environment in order to respond to changes in its conditions. Smart infrastructure systems is a combination of smart structures and the management systems that operate them. Although considerable research has been focussed on the structural aspect of embedding and installation of sensors and actuators in to the host or mother structure, the application of sensor-embedded materials and intelligent devices has so far been very limited in scope. This article describes the research efforts underway at the University of Toronto to establish a framework for developing deployment strategies for the utilization of smart materials and intelligent devices especially in the contest of infrastructure management. Two categories of smartness are being proposed, technical smartness and managerial smartness. Technical smartness is assessed in terms of hardware and network support needed for a given situation. The criteria used for categorizing managerial smartness are software support and the management system that an organization uses for data collection and decision making respectively. Based on the two criteria three modes of smart infrastructure systems are proposed. Given its objectives, scale, scope and human resources, any organization can delineate a roadmap for implementing different modes.

KEYWORDS
Infrastructure, Smart Structure, Smart System, Product Modeling, Process Modeling

1. INTRODUCTION

Although considerable research has been done on the installation of sensors and actuators in civil infrastructure for remote monitoring, there is a dearth of knowledge on effective and efficient management systems that could optimize investments in smart structures. There is a need for developing guidelines and strategies for managing the process of smart structure deployment in civil infrastructures.

A smart structure is one that monitors itself and its environment in order to respond to changes in its conditions (Culshaw, 1996). The smart structure is made of four basic physical elements: 1) host structure, 2) an array of sensors embedded or attached/installed on host structures, 3) actuator, and 4) Controllers and communication means. In civil infrastructure, a host structure may be a bridge, a highway, or a dam that has to be monitored and controlled for safe performance of its intended use. The sensors may be shape memory alloys, piezoelectric, electro restrictive and magneto restrictive materials, electrorheological fluids, fiber optics sensors based on light transmission, release of chemical etc (Akhras, 2000). The actuators may be electro-chemical, or electro-mechanical devices to impart stiffness to the mother structure-a truss- in response to the mechanical loads. A controller is the element that calibrates the signal from the sensor before the same is converted to a corresponding actuating signal (controlled release of energy) for carrying out required repair work.

The efficient deployment of smart structures (SS) requires the employment of equally smart management systems to operate them. Smart infrastructure systems (SIS) refer to the combination of smart structures (infrastructure equipped with smart systems) and the management systems that operate them. Full deployment of SIS, therefore, requires more than installing sensors and actuators on host structures. It requires a comprehensive change in the user organization to allow for full integration of the data collected into the decision-making process regarding SS design, construction, operation, interaction with surrounding environment and ultimate rehabilitation.

This paper presents a scheme for categorizing SIS (Figure 1) to allow users to define needed changes in the process of full deployment of smart systems.

2. CATEGORIZING SIS

The following assessment criteria are proposed here as framework for categorizing Smart infrastructure systems (SIS):

1. Technical smartness

    a. Hardware: Sensing /actuating devices
    b. Network: design and comprehensiveness

2. Managerial smartness

    a. Software: Integration of Data collection and decision making
    b. Management system: personnel and organizational inertia

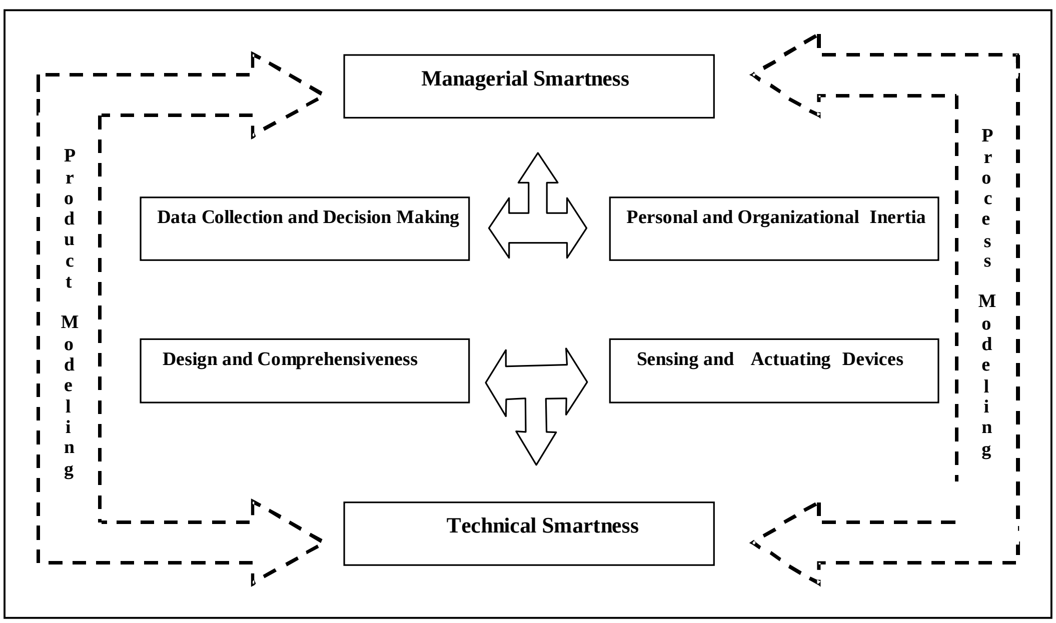

Figure 1: Categorizing Framework

2.1 Hardware

This criterion assesses the technical aspects of the sensors and actuators being deployed. It basically address the following elements:

- Level of hardware sophistication: How sophisticated are the sensors and actuators being deployed? What is the level of data reliability?
- Hardware function: What are their capabilities? Some systems can only collect data, or perform simple actuation. Other systems can achieve higher levels of interactive sensing and actuation with full integration with operating software.
- Hardware compatibility: How compatible are the hardware being deployed in their technical specification and data representation? Can data from one source be input for another device?

2.2 Network

This criterion addresses the design and specification of the sensing/actuation network. It covers the following issues:

- Scalability: a company's decision to adopt SS could be on a project, process, or company level. It could be extended to suppliers and subcontractors too.
- System design: this addresses the level of system integration. Does the system include point sensors/actuators or does it support a level of integration among sensors and actuating devices.
- IT system status: evaluates the status of company computational/IT system

2.3 Software

This criterion addresses the type and sophistication of the software system being used to control the SS. Three types of software systems could be used in this regard:

- Stand-alone systems: systems dedicated to a specific set of sensors/actuators with no connection to other software systems
- Intranet/distributed systems: systems dedicated to a host of sensing and actuating devices on a company scale and possibility connected to other applications.

- Web-based systems: systems that are connected on-line to all sensing devices and to a comprehensive set of other applications in addition to connectivity to other users and organizations systems (i.e. vendors, contractors, governments, etc.)

2.4 Management System

This criterion could be the most influential as it addresses the needed management support to SIS. It includes:

- Product Modeling: tremendous work has been conducted to develop consistent presentation of all physical products that are being used in the construction industry. Leading the way are the efforts of the International Alliance for Interoperability (IAI) which is utilizing ISO 10303 (STEP) to develop a set of Industry Foundation Classes (IFC) that provide a common platform for data exchange about construction physical products (window, door, structure, HVAC, etc.). Standardized product data modeling techniques assures easier exchange of design information among project players.

  In the case of SS a user organization needs to adopt consistent presentation of SS physical components to achieve seamless exchange of product data among manufacturers, suppliers, designers, permitting agencies, owner, contractor, users, and facility managers. Product modeling promises to achieve higher levels of performance in material management (in contrast to outdated techniques being used to control traditional materials), integrating vendor data into the design process, and facilitating design changes. Such approach help realize an adequate level of the potential of SS through integrating SS physical data in the procurement, design and operation processes leading to optimized life cycle costing.

- Process Modeling: This includes developing flexible process modules that assures synchronized workflow within different departments and across different organizations. Research is underway in different universities to investigate the development of consistent standards for conducting and describing work process ("Process Protocol", 2001). Moreover, pioneering Virtual Design Team (VDT) analysis software are already under development (Levitt et al, 1999). In the case of SS, this entitles consistent processes for acquisition, installation, operation, maintenance and more importantly the collection, modeling and management of infrastructure data in a manner that will integrate user needs into manufacturer research and developments process; integrate supplier data and order processing with user accounting system, streamlining decision-making processes between developers, owners, contractors; and revamping maintenance programs to address SS needs, etc.

- Organizational Modeling (Reengineering): This covers issues ranging from structuring decision cycles to address SS needs, fostering cross-organizational data exchange regarding SS, encouraging the deployment of SS, to threading SS benefits and knowledge within an organizational culture. This includes addressing how to design information flows within an organization to support effective SS deployment, defining decision criteria that foster optimized life cycle costing of SS, embracing open information exchange policies, fostering SS knowledge preservation. Personnel quality: evaluates the readiness of company personnel to adapt to the required change. This could include their competence in information technology practice, technical backgrounds, quality of training programs, etc.

3. MODES OF SIS

Based on the previous criteria, three modes (or levels) of SIS deployment can be proposed:

3.1 Moderately Smart System

A moderately smart system (MSS), having either an array of sensors or array of actuators but not both, is being proposed for organization that could not isolate the human interface from the management loop. Thus moderate level of smartness can be achieved by using either sensor technology for monitoring the facility or actuators to initiate the rehabilitation.

The system architecture of this model is such that either the monitoring or actuation is automated, however, the operation and data processing is not. For example an embedded sensors system could monitor the crack in a beam. The signal interpreter automatically translates the signals into useable format. The management upon receiving the data takes necessary decision to repair the crack through the available maintenance crew. This model is proposed for the organizations where advanced automation has not been adopted and human involvement in data interpretation and decision making is paramount.

3.2 Highly Smart System

In highly smart system (HSS) both sensors and actuators are used in an integrated fashion where data from sensors are tied to decision-making software and mechanism and then flow back to actuators. Moreover, the highly smart system entails wide application of sensor technology all over the organization's projects. Macro decisions are done at the top management level, while day-to-day decision about data handling and host structure actuation is mainly automated with human involvement limited to verifying system operation and data flow. Data from different geographically located sensors is received and processed under the internal decision support systems (DSS) and according to certain codes. The HSS is therefore a complete system within its own environment. However, its interface with other similar systems and the outside data generating organizations is through the traditional means.

3.3 Ultra Smart System

The difference between HSS and the ultra smart system (USS) is that the latter collects data not only from different HSS and MSS but also from other data generating organizations. The interface of USS is such that a user can access information from any geographical location including data from vendors, contractors and regulatory bodies. For example, sensors specifications are accessed automatically through the web during the design of new systems through connectivity between the organization and the vendor. Moreover, data related to the smart system should also be integrated into the organization's internal data management system. For example, data about the installation status is sent to company scheduling software to automatically update the status of sensor installation or a wireless signal from the sensor would trigger a GIS-based system to locate the sensor on the network map and update company records and the sensor network in a plug-and play mode.

Such systems will also allow for almost full automation of decision-cycles where data from sensors will feed into software system that will analyze the situation and direct actuators (or filed personnel through e-mail) to required actions.

4. SIS DEPOLYMENT STRATEGY

The three models (MSS, HSS, USS) can provide basis for initiating the use of smart structures and system into civil engineering projects. Given the scope and scale of the project, facility management organizations can plan the implementation of the most suitable of the three models depending on the following elements that should guide the development of SIS deployment strategy:

- Levels of integration: desired levels of data integration. This address the willingness of an organization to reengineer its processes to foster an integrated system for data management that encompasses data collection from sites and providers, data standardization and modeling, data and information utilization in design, execution and operation of facilities.
- User value: desired user value (accuracy, data security, timeliness, reliability, system flexibility, etc.).
- Resources: studying the required resources to implement SIS—the hardware, software and the connection technology required to implement the desired SIS mode. Resources allocated and the time earmarked by an organization to achieve certain objectives show the degree of commitment.
- Finance: defining the long-term plans for investment sources in SS. For example, a company could decide to outsource all SS installation or do it internally. A user organization could be just a user or could decide to be a user and a provider of SS technology. The investment strategy could be an aggressive one with massive short-term investments or a gradual investment mechanism. Finally, financing SS could be through equity or lending.
- Commitment: adopting SIS does not require the allocation of resources and time only, but it also requires assigning and controlling the tasks among different administrative sections and divisions of an organization. Coordination is also required among client, designers, contractors, and suppliers. Coordination can include informal and formal negotiations; exchange information and accordingly formalizing the contract in terms of assigning anticipated risk to various project partners.

5. SUMMARY AND CONCLUSIONS

This paper presented a scheme to categorize smart infrastructure systems to help interested organizations develop a more efficient deployment strategy. The scheme divides possible deployment into three levels: moderately, highly and ultra smart systems based on four major criteria: hardware, software, network and management system.

The final deployment strategy should draft a road map for interested organization to adopt (or upgrade to) one of these SIS levels based on organization objective, plans, capabilities, and commitment to SIS.

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