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Smart Construction Site: Ontology of Information System Architecture

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ABSTRACT

This paper provides a design of the Information System architecture to support a connected construction site. In order to master the diversity and the complexity of construction site processes, theories are needed that separate the stable essence of the smart construction site from the variable way in which it is realized and implemented. For that, construction site processes were mapped before linking each data path with the existing technological tools using correspondence matrixes. The results enable the definition of a proper system able to deal with the resources allocated to the construction process functionalities. The main challenge faced in this research was to identify which pertinent data is needed that activates the resources to complete each given construction task.

KEYWORDS

Smart construction; Information System; Connected site, building; design;

INTRODUCTION

Most economic sectors are required to reinvent themselves thanks to the plethora of data provided thanks to technological advances such as Internet of Things. The Information System is one critical component of this technological revolution. An Information System (I.S.) can be defined as a set of resources that enables gathering, storing, processing, and broadcasting information. Figure 1 presents schematically those functionalities. Before the "Collect" step, the right data and its source (s) are identified. Then raw data are processed, organized and structured to create some context which gives the meaning to data. Many software tools are widely used for this step of data processing. Once the data became information, it is broadcasted through communication channels to end users.

The architecture of the I.S. depends on many factors, including the purpose of the use, the required functionalities and the temporality (Lee and Yu 2012). Another crucial factor is the nature of the sector. For instance, the purpose of an I.S. intended for distribution is, at a certain level, different form an I.S. for production / services.

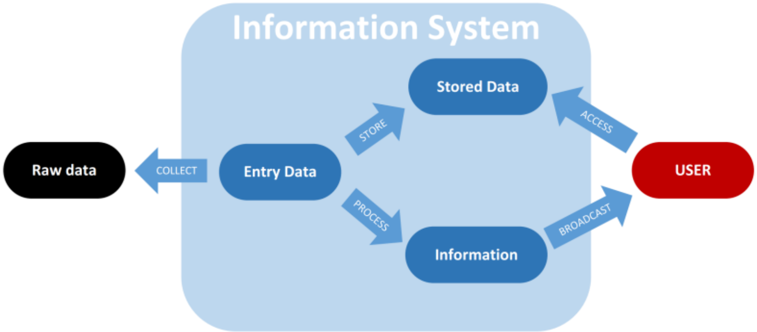

Figure 1. From data to information: the path through the Information System in construction

This article deals specifically with the I.S. in the construction industry. The construction sector is characterized by a low productivity (Dubois and Gadde 2002). The former is project-based rather than production-based, which makes its supply chain difficult to assess (Koskela and Rooke 2007). Azambuja M. and O'Brien W. (O'Brien et al. 2008) highlighted the differences between manufacturing and construction industries. The existing gap is reflected in different characteristics: the manufacturing industry is based on mass production, reduced supply variability, continuous improvement and the integration of efficient logistics while construction is limited in production (some projects per year), and highly fragmented (Wu 2009): several actors are working on the same project which makes precise management and definition of processes more subtle.

Current situation of the I.S. in Construction

Construction processes are driven by heterogeneous data such as drafts, technical notes, standard specifications, budget sheets, and planning (Hai et al. 2012; Lee and Yu 2012). In addition, still many of those documents are paper-based (Azhar et al. 2015; Kang et al. 2012). On the other hand, most of operations are not automated. For example, the accounting management is realized once, mostly at the end of each month. The construction supervisor enters manually the numbers from suppliers' invoices. Then the administrator checks the account and writes a monthly report on the financial health of the construction site.

Our view for this paper is that the information system should allow managers and directors, who deal with many construction sites, to have a clear and real-time vision of the state of progress of each construction. On the other hand, the construction site supervisor, in charge of the execution of works, should daily manage the site and anticipate the coming risks and human resources needs. Figure 2 explores the main functions the I.S. in construction and the ways to fulfill those functions.

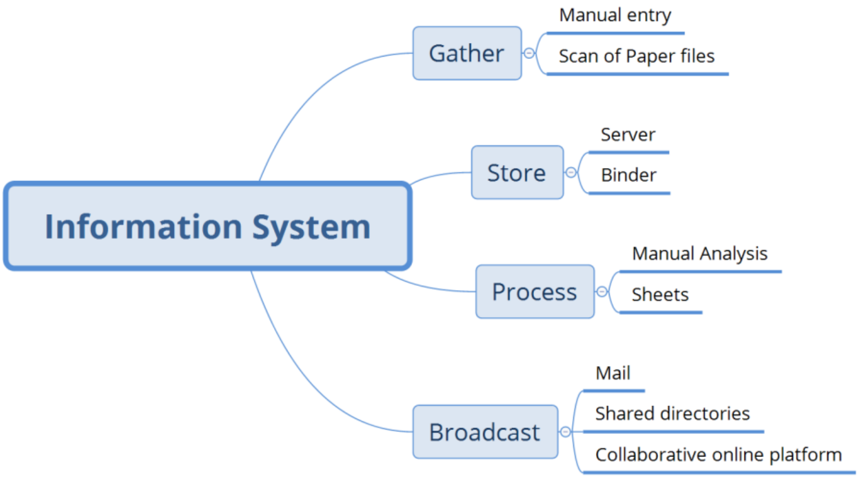

Figure 2. Main functions of the Information System in construction and ways to fulfil them

Why the need for an I.S. in Construction?
The current way of managing construction sites still lacks technology-integration (Warszawski 2003). For example, delivery notification forms contain the information needed not only to keep an up-to-date inventory of materials and equipment on the field but also to provide a better account management. Data such as the date of delivery, the type of ordered products, its quantity and the cost involved by the merchandises purchase are available. The need is for an integrated Information System that collect, store, analyze, and send the right data for the right person (or stakeholder) at the right time.

The objective of this paper is to suggest an ontology that can be used to develop the I.S. framework for smart construction site. This work can lead to a common architecture for the adequate Information System in the construction sector.

Research methodology

The results of this article are parts of a larger research project that aims to develop guidelines for managing a connected construction site. The research was realized closely with several companies and the ontology proposed in this article is the results of a 1-year work:

- Construction sites visits
- Semi-structured interviews with construction manages
- Literature research on what constitutes an I.S.

The first step was to define the functionalities of an I.S in the construction industry. Then a benchmark of tools, software and hardware was undertaken. Finally, the link between functionalities and tools has been made through a cross matrix. A series of interviews (semi-structured interviews) supported the results. We based our analysis on construction experts' feedbacks form several construction companies.

Results and discussion

Every construction project is defined in a referential in which budget, planning, and technical descriptions and standards are clear at a certain level. A well-known challenge is that those specifications change during the project lifecycle. At the same time, it is mandatory to keep information updated, and to communicate that information and to predict the risks caused by these changes. Data on materials and human resources experience the same issues. Figure *3* represents the topology of resources in the construction sector.

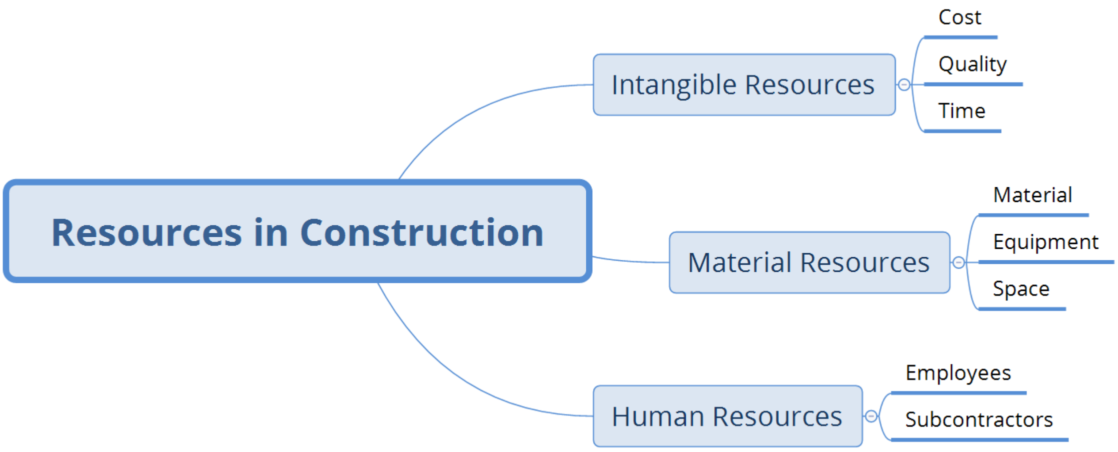

Figure 3. Topology of resources in construction

The second step is to link those identified resources with the equivalent data required in the construction site. This data is associated with strategic and operational challenges and functionalities. This work resulted in Table 1 that provides the "Relationships between challenges and managerial aspects on a construction site". The third step was to create a matrix that links the tools that support a smart construction site with the functionalities used to collecting data. This matrix is represented in Table 2. The final step is to develop the matrix linked to the distribution/ broadcasting of data. This matrix is represented in Table 3.

Table 1. Relationships between the challenges and managerial aspects on a construction site

Resources	Data	Challenges		Functionality	
		Strategic	Operational	Strategic	Operational
Time (delivery date, planning of operations)	Dates Delays Durations State of Progress Planning	Deliver in time the building in avoiding delays and cost penalties Know in real time the state of progress of each project	Have a clear vision of daily and weekly tasks Organize and adapt the planning	Define and visualize the state of progress Visualize the key dates Analyze timing to optimize the planning	Analyze available data to produce a detailed planning Optimize the measurement of the progress
Cost (the cost of a building is negotiated before the construction process and must be kept as it)	Budget Invoices Fixed prices Provisional costs Quotations	Control the risks of cost overflow Have a clear picture of project spending	Optimize daily the budget management	Visualize the financial health of the construction project Analyze financial data to optimize the budget	Continuously improve the budget management
Quality (respect of technical description, standards, safety, environmental and statutory stakes)	Specifications Standards Laws Labels Quality policy Wastes Energy consumption	Keep the project in the defined referential	Manage daily the changes in the specifications Manage a database of all the events Communicate information	Visualize the risks linked to quality, safety and environment Analyse the raw data to ensure the needed quality	Formalize the creation of a specification for project Optimize the electronic document management Automatically generate mandatory documents Conduct quality controls Identify at-risk situations
Human Resources (Employees, subcontractors or temporary workers)	Identity Employer Skills Tasks Cost	Allow the collaboration between actors Manage Human Resources Establish a relationship of trust with all stakeholders	Organize the communication Ensure the access to the information Organize people on the field Daily manage the relation with subcontractors	Visualize the involvement of collaborators Visualize the problems linked to the human resources Visualize the available workforce Analyze data linked to the use of human resources	Identify all the collaborators Anticipate the workforce needs in relation to the workload Optimize the use of the workforce Analyze productivity Communicate the required information
Material (cement, gravel, sand, welded mesh, wood or steel frames)	Type Supplier State Delivery documents Stock Storage area Wastes	Make sure stocks are sufficient when the material is needed	Manage quantities and storage areas Manage deliveries Manage the use of the materials in the right place at the right time Check the quality of the materials	Ensure that the material is accessible Visualize the risks linked to the delivery and use	Optimize the delivery management Optimize the material storage management
Equipment (small tools, vehicles, tower crane, construction machinery, formworks)	Type Owner State Authorized users Stock Period of use Energy consumption	Optimize the use of equipment	Control the use of each equipment Control the energy consumption of each equipment	Have access to inventory Visualize the risks linked to the equipment's defaults Analyze data linked to the use	Localize equipment on the field Organize the equipment management on the site
Space (Zoning, storage areas, lanes)	Localization Map Use State	Organize the use of available space	Ensure the cleanliness of the site Allow the locating of places Manage the storage on the field	Analyze the data linked to the space use	Ensure access for deliveries and storage areas Organize the zoning management

Table 2. Collect Matrix

COLLECT	Tools									
Functionalities	Digital tablet (with	Access controller	Internet of things	RFID	Geo-location	Documents	BIM	Planning system	Web	Mail
Time	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Finance			(11)		(12)	(13)	(14)	(15)	(16)	(17)
Quality, Safety and Environment	(18)		(19)	(20)	(21)	(22)		(23)		
Material	(24)	(2)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	
Equipment	(32)	(2)	(33)	(26)	(27)	(28)		(30)		
Workforce	(35)	(2)	(34)	(26)	(27)	(36)				
Use of space	(37)	(2)				(38)	(39)			
Quality control	(40)		(33)			(41)				
Paper files	(24)									
Deliveries		(2)		(26)	(27)					
Project framework						(42)				

1. Device time of use can be measured to know when the tablet is used.
2. Input-output monitoring provides the time of attendance and the authorization, and detects the presence of items.
3. Connected accessories can detect, for example, the movement of a worker or an object to determine when the task is performed.

4. Time stamped tag detection can locate tagged objects in a constrained area around an antenna.
5. GPS signal is emitted with a satellite clock message to allow the sync between data coming from satellites.
6. Time Unit analysis, risks analysis, critical tasks list, subcontractors and supplier's antecedents, delivery notes and contracts can help consider the expected project phases durations.
7. Adding the time dimension into the BIM CAD model (BIM 4D).
8. Project Phase Scheduling.
9. Information (open data platforms) on traffic, weather forecasts and strikes…
10. Requests for meetings, supplier's delays, etc. are often send by mails
11. Connected water and electric meter installed in construction site facilities allow for bill control.
12. Kilometric rates through geolocalization could improve fuel management for logistics.
13. Invoices, quotations are the main source of information (financial aspects).
14. Quantities and Cost can be filled in the model for efficient project costing (BIM 5D).
15. The Planning system can give the information on the timing of expenditure during the project lifetime.
16. Raw materials prices and law changes are easily spotted on the web.
17. Account manager's updates are often received by emails.
18. Quality control can be performed with the embedded camera and other technologies such as Tablets.
19. Connected dumpster allows the identification of users, the nature of deposited waste, and weighing (Goodrum et al. 2006).
20. Wastes can be tagged in order to know which of waste there is on the dumpster
21. A Lone Worker detection can be done with such a technology
22. Accident report, bills, Quality control and Standards are the main indicators for Quality and Safety.
23. Periodic controls can be planned to ensure a good quality tracking.
24. Delivery notes and other paper files can be scanned with the embedded camera.
25. Connected containers can track the material volume in real time.
26. Identification of items is easier as well as accuracy in inventory control (Wang et al. 2007)
27. Location of Items, Machinery and Workers on the construction site and on the road for deliveries (Pradhananga and Teizer 2013).
28. Technical sheets and Delivery notes provide the necessary information for the use of material and equipment.
29. Each item is referenced in the model for computing an ordered list of pieces.
30. Planning system provides the desired delivery and release dates for all the equipment.
31. Price changes monitoring and new products release can be gathered through the web network.
32. Visual identification of equipment can be performed by the embedded camera.
33. Embedded sensors can provide the state of the equipment and its use.
34. Connected clothes can prevent and measure painfulness, noise and fall detection to ensure safety of workers (Teizer et al. 2010).
35. Progress monitoring can be performed through photo analysis (Teizer and Vela 2009).
36. HR records, Workload curves, Accident and Activity report contribute to better know the construction company employees.
37. Areas monitoring through image processing can organize the space on the construction site.
38. Construction site installation plan provides all the information to install and move along the site.

39. BIM tools allow for the organization of the space and specific areas on a construction site (Gore et al. 2016).
40. Mistakes identification from image processing.
41. Quality process control notes.
42. Standards and company policy drive the project and help to structure the main phases.

Table 3. Broadcast Matrix

BROADCAST	**Tools**							
Functionalities	**BIM**	**Digital Tablet**	**Electronic Document Management**	**Product Life Management**	**Communication Channel**	**Internet Of Things**	**Graphical User Interface**	**Logistics**
Project Framework	Digital Twin		Document database	Access right management	Alert generation			
Dashboard							Dashboard with processed data	
Inventory and Stock management						Identification of items	Real-time items tracking	Connected warehouse man
Delivery tracking		Delivery notes scan			Alert			
Information transfer				Access right	Updates			
Mandatory document access			Automated forms					
Alerts					Specify target		Add new type	
Automated data send				Access right	X			
Optimized zoning	Zoning by use							
Equipment management						Geolocation	Display location of equipment	
Access rights management				X				
Identification of workers				Access right		Badge access control		

Organize document management			X	Access right				

CONCLUSION

An information system is a set of resources that collects, stores, processes and distributes information. Today, the development of new technologies around digital technology is driving most economic sectors to reinvent themselves. The information system should be designed to enable easy, organized, and secure information access

The construction sector has always processed lots of information of different types: plans, technical notes, standards, budget, planning, etc. The tools today to collect, store, process and distribute information are not up-to-date to face current challenges of the construction industry.

The first step of this research work was to define the functionalities of an information system in construction. In a second step, the inventory of tools was identified and a matrix crossing the expected functionalities for the site information system was developed. This research is a first stepping stone to define common guidelines for the Information System in the construction industry.

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