

A Review of ICT Applications in Construction

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Abstract— In this review paper we compiled and demonstrated the trends and patterns of the research published on ICT Applications in the construction industry over the past two decades (1996-2016), through employing a five phases profiling methodology which generated an acceptable set of 68 out of 202 articles and papers indexed by Elsevier's Scopus database. This paper reviews the utmost academic ICT applications and proposals/ initiatives in the construction industry taking an advantage of a previously generated research journal on ICT Technologies and Construction Tasks. A resulting classification of 11 categories of ICT Applications as appeared in literature along with their corresponding authors and dates was provided and discussed.

Keywords— ICT Applications, Construction industry, Literature Review.

I. INTRODUCTION

According to Adwan and AlSoufi (2016), very few rigorous scholarly review endeavours were found investigating the ICT Applications in construction industries and this is due to different research intentions, objectives, purposes, types of ICT, duration of review, quality of review's methodological and analytical findings, and implications. In the current paper we build on the previous empirical findings, mentioned as reference (Adwan and AlSoufi, 2016) to demonstrate the actual corresponding ICT Applications and proposals/initiatives in the construction industry.

The aim of this paper is to review the ICT Applications and proposals/initiatives in the construction industry over the past two decades (1996-2016). This research has implications for the beginning researchers, practitioners and universities of the construction field and forms the foundation for profiling other databases and specific types of construction related ICT journals and papers in this area.

A group of quality academic outlets was dedicated to publish research on ICT applications and on construction. Scopus is represented as one of the world's largest database of a trustworthy and peer-reviewed research which indexes most of those outlets (i.e. 20,500 titles and subject areas from thousands of publishers) all around the world (Adwan and AlSoufi, 2016). Based on a 5 phases profiling methodology, this research intends to classify the ICT Applications or initiatives considering the previously investigated ICT Technologies and construction Tasks. From the empirical findings (using 4 mainstream keywords), initially 202 research works were identified from the Scopus

database during the period 1996–2016. After assessing the 202 publications, 68 articles and papers were finally considered relevant and taken forward for further investigation.

II. ICT APPLICATIONS

Table 1 demonstrates the categorization of ICT Applications and the corresponding authors in construction industry. There appears 10 application categories including, BIM based ICT applications, modelling based ICT applications, computer based Training ICT applications, decision based ICT applications, mobile, wireless & tracking based ICT applications, miscellaneous ICT applications, knowledge management based ICT applications, virtual based ICT applications, project management based ICT applications, simulation based ICT applications, and web based ICT applications.

TABLE I
CATEGORIZATION OF ICT APPLICATIONS AND THE CORRESPONDING
AUTHORS

| BIM based ICT Applications | Modelling based ICT Applications | Computer based Training ICT Applications | Decision based ICT Applications |
|---|---|--|---|
| Penttilä (2006) Jensen and Johannesson (2013) Jacobsson and Linderoth (2010) Inyim et al. (2014) Wang et al. (2014) | Berente et al. (2010) Brewer and Gajendran (2009) Alkalbani et al. (2013) Chien and Barthorpe (2010) Anumba et al. (2002) | Evia (2011) Keraminiyage et al. (2008) Zhu et al. (2010) | Benza et al. (2007) Jacobsson and Linderoth (2012) Rankin and Luther (2006) |

| | | | |
|--|---|---|--|
| Chen et al. (2015) Chaisuparamsikul (2006) Davies and Harty (2013) Solnosky (2014) | Ekholm and Molnár (2009) Chaisuparamsikul (2006) | | |
| Mobile, Wireless & Tracking based ICT Applications | | Miscellaneous ICT Applications | |
| Leem and Kim (2013) Perkinson et al. (2010) Riaz et al. (2011) Bowden et al. (2006) | Nielsen and Koseoglu (2007) Molony (2008) Suman et al. (2009) | Al-Neshawy et al. (2011) Riaz et al. (2011) Shin (2012) Şahin and Kurum (2009) Lessing et al. (2005) | Azhar et al. (2015) Lin et al. (2014) Froese (2010) Benjaoran (2009) Rezgui and Miles (2010) |
| Knowledge Management based ICT Applications | Virtual based ICT Applications | Project Management based ICT Applications | Simulation based ICT Applications |
| Tang et al. (2010) Graham and Thomas (2005) Zhang and Ng (2013) Chien and Barthorpe (2010) | Dehlin and Olofsson (2008) Sher et al. (2009) Christiansson et al. (2011) Chien and Barthorpe (2010) | Wong and Lam (2011) Alkalbani et al (2013) Arnold and Javernick (2013) Nielsen et al. (2007) Jacobsson and Linderoth (2010) | Rankin and Luther (2006) Benza et al. (2007) Chaisuparamsikul (2006) |
| Web based ICT Applications | | | |
| Chien and Barthorpe (2010) Jacobsson and Linderoth (2010) Jacobsson and Linderoth (2012) Hassan and McCaffer (2002) Zavadskas and Kaklausk(2008) | Peansupap and Walker (2005) Oladapo (2005) Polat and Donmez (2010) Tang et al. (2010) Lam et al. (2010) | Pathirana et al. (2012) Nielsen and Koseoglu (2007) Alkalbani et al. (2013) Benza et al. (2007) Dave and Koskela (2009) | Jardim and Grilo (2010) Anumba and Duke (1997) Chaisuparamsikul (2006) |

BIM-BASED ICT APPLICATIONS:

Penttilä (2006) explored the integration of BIM with CAD modeling to produce BIM based CAD systems which would shorten project spans and costs. Moreover, Jensen and Jo'hannesson (2013) investigated the implementation of BIM in the Nordic countries in terms of drafting techniques including BIM, IFC (industry foundation classes) compliant BIM in comparison with CAD applications. Additionally, Jacobsson and Linderoth (2012) studied the exploration of users' general perceptions of ICT impacts of the post adoption stage in Swedish construction companies. Moreover, Inyim et al. (2014) presented SimuleIcon as an economic and environmental impact analysis ICT utility that uses a NSGA-II as a multi-objective GA. It is designed as an add-on application to Autodesk Revit Architecture that combines BIM with optimization techniques. Furthermore, Wang et al. (2014) proposed a framework for a BIM-based integrated construction engineering and project management education platform (BIMIEP) that allows the exchange of knowledge about construction engineering and project management (CEPM) education among the tools of ICT. BIMIEP allows for the interoperability across different ICT

tools, among different stakeholders and data sharing across projects and companies. This would allow a sizable database with project models and data to be built to support CEPM education. Also, Chen et al. (2015) proposed a conceptual framework for synchronizing information and bridging BIM and building (BBB) throughout a projects life-cycle. The framework consisted of several layers, including a physical layer (representing the AECO activities throughout a project life-cycle), BBB technologies, a BIM layer, and the central database set up between the physical layer and the BIM layer. This tool was said to plan their BIM implementation strategies and improve the project management performance. Chaisuparamsikul (2006) demonstrated a BIM based VMS (Virtual Model System) application which offers the innovative data collaboration, integration and sharing capabilities between CAD and software applications such as building code check, submission and compliance, energy performance simulation and prediction. The VMS builds on a framework or platform of BIM and improves the traditional design process that has to recreate the same building model as much as seven or eight times (architecture, structure, mechanical, electrical, plumbing, energy analysis and simulation, construction documents, lighting, code checking, cost estimation etc.). Davies and Harty (2013) discussed the development of scales aiming to measure perceptions of BIM use in a survey of employees of a UK construction contracting organization. Moreover, Solnosky (2014) discussed the development of an integrated process model from the perspective of a project which has utilized BIM-enhanced methodologies.

MODELING -BASED ICT APPLICATIONS:

Berente et al. (2010) investigated an architectural project carried out by one of the leading architect offices. The project consisted of a radical architectural design and a shift to 3D (from 2D) computer-aided design (CAD) technology across participating design teams. They aimed to explore the technological shift and the associated interactions among several design firms involved in the project to better understand the levels of information pooling and physical interaction and their interactions with object world congruence. The architect office began to use highly sophisticated 3D CAD (i.e. CATIA™) software developed for the aerospace industry and widely utilized in automotive and shipbuilding. Moreover, Brewer and Gajendran (2009) investigated the shared CAD models to facilitate design and costing/ - industry-wide standards and procurement protocols. Alternatively, Alkalbani et al. (2013) ran a contractors survey to investigate the most ICT investment in organizations. The results, from those respondents verified that the main area for ICT investment was CAD, scoring 26.67%. In their study to enhance the effectiveness of construction management in the Taiwanese construction industry, Chien and Barthorpe (2010) mentioned that Computer-Aided Design and Drawing (CAD) software was used mainly as a product design tool at which the construction companies would increasingly use CAD software in the future. Moreover, Anumba et al. (2002) studied the Concurrent Engineering (CE) at which CAD, CAM, CAE and CAPP software applications were the most Simulation methods. Chaisuparamsikul (2006) introduced and implemented a VMS framework which linked and

shared object-based models in CAD software (Autodesk Revit Building) with performance-based models in thermal simulation software (DOE-2.1E). Alternatively, Ekholm and Molnár (2009) found out that technical documentation, based on 3D-CAD and building information models, was exchanged through web-based project networks through e-mail attachments while time schedules for work planning and deliveries were produced by commercial software.

COMPUTER-BASED TRAINING ICT APPLICATIONS:

Evia (2011) studied the digital divide in the U.S. construction industry by determining the feasibility of using computer-based training (CBT) solutions on the topic of workplace safety for Hispanic construction workers. They discussed the adoption of BuildIQ's Jobsite Safety 1 course which is part of a catalog of web-based training materials for construction workers. To facilitate administration and coordination of the EURASIA project, Keraminiyage et al. (2008) presented a Construction distance education system (VEBER) for students who are geographically prevented from attending the programs hosted by an educational institution established physically or virtually. VEBER was based on an open source toolset (Moodle). Moodle is a dynamic data driven web application written in PHP and supports number of different backend DBMSs (MySQL) is used as the backend. VEBER was comprised of a file hosting tool that shares mechanisms including a common document repository and a private workspace to keep and share private and confidential documents securely, a survey tool to aid data collection during the project and a file hosting tool to facilitate joint paper preparations and discussion forums which include chat, online workshops and related learning materials, and library services. Zhu et al. (2010) proposed Concept maps (CMAPs) for students to study a photovoltaic system. Different from methods that are based on graph theories, this study explores the idea of using concept mapping to elicit the knowledge structures of students and measuring the similarity of knowledge structures through concept similarity analysis.

DECISION-BASED ICT APPLICATIONS:

In a TMD-NIS project, Benza et al. (2007) proposed a Decision Support System (DSS) for the detection and monitoring of Hazardous Material (hazmat) transportation on the road infrastructure project. A group of assessment applications was performed by the partners of the project, including, an image processing system to identify the ONU codes on the hazmat plates installed on each truck, an on-board computer system to store and transmit information related to the hazmat physical conditions, vehicle's locations and performance measures. The project also provided a GIS utility, available on the web, to track in real-time hazmat vehicles, to analyze data about hazmat flows and to visualize the risk index for the highway from the toolbar barriers of St. Isidore (Nice) to the Ventimille. The DSS was based on three different layers by the integration of hardware and software systems, including, detection and monitoring system, a common database to store information acquired by both the active and passive systems, risk definition module and a web-GIS (Geographic Information Systems) user interface. Rankin and Luther (2006) discussed a framework of innovation and the uses of ICT at which the relevance of

the framework was summarized by a discussion of how these interrelated analyses were applicable to the decision-making process within a particular firm and of the mechanisms required by the industry to improve the innovation process. The case study examined the response of a construction company to a single innovation at which decision-making tools aim to measure the maturity level of available ICT.

WEB-BASED ICT APPLICATIONS:

In a survey of the Taiwanese construction industry, Chien and Barthorpe (2010) found that amongst the Communication systems, e-mail and Intranet for internal communication tools were the most popular web based ICT applications. Jacobsson and Linderoth (2010) discussed the usage of e-mail and mobile phones for Communication, collaboration and information sharing web based systems. Similarly, Hassan and McCaffer (2002) studied the business and ICT trends in the European LSE construction industry at which several web based ICT applications were implemented including, email, Video conferencing, internet, intranets, QA systems and documents control and Communications systems, while Oladapo (2005) investigated the use of ICT in the Nigerian construction industry revealing that the internet communications was one of the main uses of ICT in the construction industry. Lam et al. (2010) found the heavy usage of internal intranet external extranet as communication web based applications. Jardim-Goncalves and Grilo (2010) discussed the BIM applications under the Cloud Computing paradigm being a type of web-based technology. Web-based intelligent & biometric applications were proposed by Zavadskas and Kaklauskas (2008). Alkalbani et al. (2013) demonstrated the email, database and web browsing as three web based applications. Furthermore, Peansupap and Walker (2005) undertook three case studies at which one company found that it was difficult to exchange information and knowledge and improve the company's construction processes between group members from regional offices. Thus, the company thought of building a collaborative system (ICT groupware application) at which it was based on a database environment as a development tool. Another case study was the production of a web-based collaborative application. Also, they adopted stand-alone applications including, e-mail and file-transfer protocol (FTP). In a study that explores the marketing management and practices of Turkish construction companies, Polat and Donmez (2010) demonstrated the usage of Web banners and Web popups being the most popular applications of communicating with clients. Moreover, Tang et al. (2010) studied the Knowledge and INFORMATION Management practices (K&IM) in the aerospace and construction industries. The commonalities were that both have implemented hardware, software and 'criticalware'. Hardware included databases, networks, servers, communication systems, phone and PDA, personal PCs, shared drives and physical archives, whilst software included data and document management systems, process management systems, intranets, extranets, protocols, shared repositories, wikis, blogs, email, yellow pages, Web 2.0, XML tools and intelligent decision. An intranet-based collaboration tool (Champion) was also included. Furthermore, Pathirana et al. (2012) employed Wiki ICT

application. Wiki is a Web 2.0 collaboration tool that was aimed to support small student groups research in hydrology. In addition, Nielsen and Koseoglu (2007) proposed an implementation scenario of wireless networking application for a multisite tunneling project in Turkey which had communication and collaboration. The system was aimed to share documents, access data and control project details. On-site engineers used mobile voice systems (Pocket PC, Tablet PC, etc.) to receive/transmit information from/of site. WLAN and the Internet maintained the time consumption and allowed for videoconferencing through mobile devices. Collaboration was also applied through mobile collaboration and was useful for the database development of the project-specific web page. Software may have included resource planning, progress control and quality control. According to Benza et al. (2007), the previously mentioned DSS was accessed by a web-GIS interface application. The web-GIS interface tracks and analyzes real-time hazmat transports and hazmat risk data respectively. So, based on a Microsoft Map-point web service application, the system could produce real-time maps (Navteq digital maps). Dave and Koskela (2009) implemented a social web application to simply solve a particular knowledge sharing problem within an organisation's concrete pumping business, that is, to create knowledge by taking employees' ideas through an iterative cycle of discussion. Also, Anumba and Duke (1997) provided information about the computer-supported communication and collaboration tool including, the Electronic mail (e-mail) is regarded as the fastest, cheapest communication medium between people who have access to a computer network, Video Conferencing and the World Wide Web (WWW). Finally, Chaisuparamsikul (2006) presented the development of a data mapping engine in a VMS framework server to accomplish the task of fully converting CAD information models to energy performance models on the web through web browsers.

VIRTUAL- BASED ICT APPLICATIONS:

Dehlin and Olofsson (2008) proposed an MK3 project-oriented evaluation model (financial evaluation tool) to evaluate the implications of ICT investments in construction projects. The models' application was illustrated using a case study of a construction project using 3D and VR for coordination and evaluation. The technical equipment and VR platform (Walkinside) consisted of commercial visualization software, PC computers and servers. Walkinside was responsible for importing CAD formats. Presentations of the VR models were done with 2D-projectors/monitors. The design was carried out using a number of 3D CAD applications including, Solidworks, Tekla Structures, AutoCAD, Microstation and Intergraph's PDS system. Sher et al. (2009) demonstrated the application of Noldus Observer Pro as a video analysis software to record designer team collaborations at which it facilitates the collection, management, analysis and presentation of observational data and allows researchers to view video footage, score the frequency of certain behaviors and note those interaction behaviors. Data was collected in three experimental conditions, two of which were through electronic whiteboard and a high bandwidth 3D virtual world. Christiansson et al. (2011) discussed the virtual innovation in construction (VIC) project aiming to develop an ICT

supported methodology (VIC-MET) to let building end-users participate in with building designers in fulfilling their building requirements. The method gives the advisors and the client a set of tools to support the process. The method assumed that users have knowledge to contribute with the construction project. The advisors' role is to create a design process where the user wishes, ideas and needs come forward, and to include them in line with all other requirements for the project. The method is holistic and aimed at all types of projects and all phases of construction. Several ICT tools were used to accompany the project. Those included 3D Data collection and modelling tools, Communication and collaboration such as WWW and Visualization and interaction such as 3D animation and virtual reality (based on Nintendo Wii Remote equipment). Chien and Barthorpe (2010) ran a survey and found out that the virtual reality application scored 76% of the most useful tools in improving the effectiveness of marketing and communication.

MISCELLANEOUS- BASED ICT APPLICATIONS:

To monitor the thermal and moisture conditions in repaired concrete building facades, Al-Neshawy et al. (2011) developed a relative humidity and temperature monitoring network system (RHT-MNS network and RHT-MNS monitoring software). The basic components of the relative humidity and temperature monitoring networks are moisture and temperature sensors, a data acquisition device and the software application for data processing. The RHT-MNS monitoring software was developed using Microsoft Visual Basic 6.0 to connect the network system to the host computer aiming to collect and analyse the relative humidity and temperature data, configure the RHT-MNS system, connect with the network controller, calculate the relative humidity and temperature data and process these data into charts. Furthermore, Riaz et al. (2011) presented the architecture for development of a central system for plant management (SightSafety) that could integrate several heterogeneous data sources' technologies with management information system (MIS) software that shares information aiming to provide a health and safety management solution on construction projects. Şahin and Kurum (2009) discussed a landscape-scale ecological monitoring method for major construction projects that is able to verify the accuracy of environmental impacts assessment (EIA) predictions. Moreover, Shin (2012) provided the concept, Community Informatics- Supported New Urbanism (CI-NU) that recommends ways of communication and collaboration between community informatics practitioners and new urbanists to accomplish their shared goals of integrated community development through a community-based planning process. Azhar et al. (2015) investigated the perception of the integrated project delivery (IPD) as a way to improve project delivery effectiveness. The adoption of Integrated project delivery (IPD) as a delivery system standard for collaborative practice on public sector construction projects. The adoption of ICT (collaboration software applications) fosters IPD by assisting users from multiple locations to keep all communications, documents & drawings, forms and data in one single place. To study the occupational safety in construction, Lin et al. (2014) found that safety inspection process was suffering from several

drawbacks and requires tools for user-centered information and communications technology could significantly reduce such drawbacks. Amongst the drawbacks, inspection process suffers from lack of standardized processes and documentation, information restricted access to, repetitive data preparation, and limited availability of safety. They discussed a centered design approach aiming to develop and evaluate an iPad application (iSafe) that overcomes drawbacks and improves safety inspections to generating consistent and high-quality inspection records and therefore limit the potential of advanced safety and health data analysis. In the production In the first step of the iSafe production, a paper prototype was developed and evaluated. In the second step, an ICT application prototype running on an iPad was developed and evaluated and containing most of the key functions. To support the unified approach to project management, Froese (2010) discussed the application of a unified approach to project management which is an ICT platform that allows different views to be represented, inter-related, accessed, and utilized in an efficient manner by all project participants. This approach includes the development of some applications including, IFC-based data exchange, information aggregators, Online Analytical Processing (OLAP), 4D CAD systems and organizational simulation. As a collaborative approach for 5 SME sized contractors, Benjaoran (2009) developed a Cost Control System using MS Access and XML. The application aimed to monitor the progress of project costs and to make a real-time comparison with the bill of quantities (BOQ). The system development required a synchronized database management system (Microsoft Access) at both construction sites and the contractor's office and Visualbasic (VBA) for application codes and internet plus XML formatted file. Furthermore, Rezgui and Miles (2010) explored the adoption of ICT-enabled alliance modes of operation by SMEs in the construction sector to gain more competitive products and services advantages. They provided discussion about a legal and contractual software. Alternatively, Lessing et al. (2005) discussed the need of frame solutions, electrical and sanitary installations and façade systems so that in order to minimize defects and create an effective process, technical systems are developed in separate product development processes, where the design is tested, adjusted and developed to a high level of completion. These systems are then used in the design and production of unique housing projects. The technical systems include frame solutions, electrical and sanitary installations and façade systems with different levels of flexibility. For the two discussed cases, both companies used different CAD-applications for design modeling purposes and was preparing to install an ERP-system with integration facilities.

MOBILE, WIRELESS & TRACKING-BASED ICT APPLICATIONS:

Aforementioned in web-based applications section that Nielsen and Koseoglu (2007) proposed an implementation scenario of wireless networking application for a multisite tunneling project in Turkey which had communication and collaboration capabilities. The system was aimed to share documents, access data and control project details. The wireless networking application enforced the on-site engineers to use mobile voice systems (Pocket PC, Tablet

PC, etc.) to receive/transmit information from/of site. Moreover, Molony (2008) studied the role of mobile phones being a cost saving device in the Tanzanian construction sector while in Slovenia, Suman et al. (2009) developed a methodological concept 'Reengineering of the construction process (RCP-model)' to captures the business process reengineering (BPR) philosophy besides the potentials of (mobile ICT) aiming to create a communication environment which would assist the dynamic communication and cooperation between project actors and project data. Therefore, implementation of mobile ICT components (PDAs, mobile phones, table computers) was thought of enhancing the extension of communication system. The implemented Mobile ICT application included a collaborative project management portal (Project Office Portal) tool to monitor schedule and project cost. The web based side of the application was based on virtual data storage in a web-environment that acts as a dynamic sharing point of all data so every participant has access to all project activities including costs and project documentation. Furthermore, Korea's ubiquitous city (u-city) construction project is facing problems of operating costs, specialization of cities, and connection with industries in pursuing the project. To solve these problems, Leem and Kim (2013) proposed a u-city service classification system to develop it successfully by means of providing balanced city service through ICT, including, a Geographic information system which is a computer system capable of integrating, storing, editing, analyzing, sharing, and displaying geographically-referenced information and a Global positioning system: System enables a GPS receiver to determine its location, speed, and direction. Moreover, Perkinson et al. (2010) proposed integration between GPS and ICT infrastructure to develop a Total Jobsite Management Tool (TJMT). To develop the ICT infrastructure they designed a project database and 3D models. The 3D models were then transferred to the on-board component to be used by the machine operator. The on-board component consisted of an available machine control system which includes a base station, GPS receiver(s), and an on-board computer. The GPS receiver communicated with the GPS satellite constellation and the base station to provide continuous positioning data. Furthermore, Riaz et al.(2011) investigated the mobile computing and RFID tags for automatic data collection for plant security.

KNOWLEDGE MANAGEMENT- BASED ICT APPLICATIONS:

Aforementioned that Tang et al. (2010) studied the K&IM practices. They came with a Knowledge and information management software application within the undertaken case study. However, in Ireland, Graham and Thomas (2005) proposed a tailored Knowledge Management System to meet an Irish construction company's needs based on different organizational knowledge sharing practices. They mentioned tools including, Knowledge Online, using Internet technologies; ikonnect, a web-based application; 'Knowledge Cafes'; and web-based, knowledge-sharing tool. Also, Zhang and Ng (2013) applied the existing theory of social psychology to study knowledge sharing in Hong Kong construction. An integrated model (TPB) regarding knowledge-sharing intention was developed and tested. ICT

could facilitate the KM process by removing temporal and physical distance, providing access to retrieve relevant information and accelerating the knowledge sharing time. In a survey run by Chien and Barthorpe (2010), findings revealed that KM software scored 29.4% and scored 67% in the level of usefulness to improve the effectiveness of knowledge management from existing KM systems.

SIMULATION- BASED ICT APPLICATIONS:

Chaisuparasmikul (2006) mentioned the presence of DOE-2 as a performance simulation software that calculates the heating, cooling, lighting loads and the energy consumption of primary plant equipment as simulation details. Also, Benza et al. (2007) proposed an Optical recognition system to identify the hazmat vehicles at which the symbols which define the risk can be in different colors and model. The project was based on the identification of the plate danger code. In addition, a prototype of an image acquisition system was set up in a toll-bar in France. The system included a video camera installed in each passage of the highway toolbar. So, after the acquisition of the image, a software treats the picture in order to detect the numbers inside the orange rectangle.

PROJECT MANAGEMENT-BASED ICT APPLICATIONS:

Wong and Lam (2011) discussed the availability of an online project information exchange system at which they were used both internally by internal staff and externally with outside parties to update and complete records of contractual documents and architect instructions, project budgets, payment data, monthly forecast, drawings and as technical and procedural guides. According to a survey on the Omani construction industry, Alkalbani et al (2013) considered that project management and finance equally scored 26.67%, with document management system in 3.33% of cases. Arnold and Javerck-Will (2013) discussed the challenges of using the Project Management Software Systems (PMSS) in the AEC industry and offered suggestions for improvements. AEC industry and software vendors were challenged to successfully implement PMSSs. There existed several Web-based and project-based PMSS applications in market. According to Nielsen et al. (2007), the eLEGAL project allowed for the generation of a contract configuration and negotiation tool (ICT Contract). This tool aimed to improve project business relationships in construction projects which leads to more trust in using the technology and reduced number of disputes. ICT Contract produces model contracts for construction projects which can be negotiated by using a “virtual negotiation room” on the Internet in which different parties of a construction project are automatically guided while being linked together. Moreover, In Sweden, Jacobsson and Linderoth (2010) made a distinction between Construction company permanent’s use of ICT and its use in temporary company (building and construction projects) thus ICT applications which were mainly designed for projects. Within the case company they found a total of 60 different ICT systems at which The Operation System represented the most important link between the permanent and the temporary project companies and consisted of five sub-systems. Those included, a Customer Relation Management (CRM) System; Small Project Planning systems for the planning of smaller projects; Large Project Planning systems

for the planning of larger projects; Cost Estimation System for the calculation of project costs, containing standard costs and recipes; and E-commerce system linked to major suppliers. In addition, along with this operation system, they demonstrated the availability of another 5 separate applications including, Database for sharing documents among contractor, subcontractors and client; Digitized survey; E-commerce system linked to major suppliers; E-mail and mobile phones and a 3D-based Building and Information model (BIM).

III. CONCLUSION

Continuing from a previous research work, we demonstrated the trends and patters of the research published on ICT Applications in the construction industry for 20 year. This paper reviewed the best academic ICT articles aiming to elicit the ICT Applications and proposals/ initiatives in the construction industry based on a generated classification of 11 ICT Applications’ s categories.

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