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Enterprise architecture-based ISA model development for ICT benchmarking in construction-case study

Ehab Juma Adwan[1], Ali Al-Soufi[2]
[1]Department of Information Systems, University of Bahrain, Zallaq, Bahrain
[2]ICT Consultant, Information and eGovernment Authority of Bahrain, Muharraq, Bahrain

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ABSTRACT

Building on a coincided in progress paper, this paper constructs and evaluate an information systems architecture (ISA) model for the Bahraini architecture, engineering and construction (AEC) sector, from the lens of enterprise architecture (EA). This model acts as an information and communication technology (ICT) barometer tool to identify and benchmark the ICT's gaps, duplicative levels, and future investments. Following the design science research, this paper and throughout a utilization of a tailored version of the open group architectural framework (TOGAF), embedded into a rigorous case study approach, the construction, testing, and evaluation of the conceptual ISA model is approached to benchmark the ICT measurement. Empirically, the study revealed the appropriateness of the model and the ability to identify the availability of 28 groups of 38 individual ICT applications in the Bahraini AEC sector and benchmark them to score an average of 18.5% against 17 countries that scored an average of 18.6%.

Corresponding Author:

Ehab Juma Adwan
Department of Information Systems, University of Bahrain
Bahrain International Circuit, Zallaq, Bahrain
Email: eadwan@uob.edu.bh

1. INTRODUCTION

The AEC sector is a highly visible player in countries' growth, considering that the effects of changes in the construction sector impacts all levels of the economy. However, our reviewing revealed lack of previous research endeavours on empirically grounded and exploratory information and communication technology (ICT) approaches to benchmark the ICT applications in the architecture, engineering and construction (AEC) enterprises. ICT benchmark research is focused on the structuring, standardizing and generalizing of IT implementation within enterprises. However, initiatives to benchmark ICT applications in AEC were found relatively limited, in comparison to other sectors and in several countries, at which Bahrain is no exception. Moreover, the usage of IT-barometers to benchmark ICT diffusion in construction tends to be ineffective as the AEC sector is yet not well defined, nor understood, and lacks common definition. This paper is coincided with another in progress paper which develops a business model (BM) for AEC sector. This paper commences by highlighting key findings from the other paper and building on it to develop and evaluate an information system architecture model (ISA) to benchmark the ICT applications penetration levels.

Enterprise architecture (EA) practice provides analysis of common core elements of a socio-technical enterprise, their interrelationships within and out boundary in order to manage complexity. From the lens of the EA and through a tailored the open group architecture framework (TOGAF) based

methodology, this study is aimed to achieve three objectives: firstly, construct an ISA model of the AEC enterprises, secondly, benchmark the ICT applications, and thirdly, compare the resulting domestic penetration levels to the Gulf Cooperation Council (GCC), Arab and regional countries, all throughout a literature review and a case study to benchmark the domestic ICT applications. Findings of this paper indicate the appropriateness of the ISA model to benchmark ICT applications, contextualized for AEC sector. This approach should build on existing knowledge and findings from research into generic ICT applications benchmark which should also be based on reference business models.

The paper is organized as follows: section 2 explains reviews related work to the problem at hand. Section 3 introduces the design science research (DSR) methodology and executes the 1st phase until the 3nd phase of the DSR. Section 4 elaborates on the initial constructed ISA model through case study analysis of the 4th phase. Therefore, collected data is analysed, the empirical findings are pronounced, demonstrated, evaluated and communicated according to the 4th, 5th and 6th phases of the design science research methodology (DSRM). Section 5 concludes and provides future recommendations of the study workout.

2. LITERATURE REVIEW

2.1. Enterprise architecture and TOGAF

Hinkelmann *et al.* [1] defines EA as a blueprint that describes the elements and relationships of an enterprise and organizes the business processes, organizations, data, and information technologies accordingly. Furthermore, EA entails graphical models for the generation of architecture description artifacts at which the architecture description is a tool that solves knowledge complexities in enterprises. The representation of knowledge is interpreted either in a human graphical interpretation or in machine interpretation. For the development of architectural model, an EA framework (EAF) is utilized to define and describe the architectural artefacts and relationships. International organization for standardization [2] defines EAF as ‘‘fundamental concepts or properties of an enterprise in its environment embodied in its elements, relationships, and in the principles of design and evolution”. Reaserchers [3], [4] believe that EAF provides a collection of processes, techniques, artefact, and reference models for the production and use of EA description. Several EAFs were utilized in industries for different purposes. Department of defense architecture framework (DODAF) was created for the defence sector [5]. The federal enterprise architecture framework (FEAF) was created for the federal governments [6]. Zachman Framework represents the 12 perspectives of different stakeholders [7]. Alternatively, TOGAF acts as an iterative framework that provides methods to assist the production, use, and maintenance of EA [8]. TOGAF categorizes enterprise levels into architecture vision (AV), business architecture (BA), information systems architecture (ISA), encompassing data, app, and technology architectures. BA considers the enterprise strategy, objectives, and stakeholders’ interests. The BA document and the architecture vision document are illustrated in Appendix 1 and Appendix 2 consecutively. The ISA level, however, encompasses the application-level aspects which map the information needs on the enterprise’s business needs.

2.2. ICT penetration in construction

Resulting from the SLR and meta-analysis approaches and based on the insights of [9], [10], the current study collected the most common ICT apps in the AEC sector from 17 countries, Table 1 lists a set of 36 reviewed articles. Appendix 3 demonstrates the empirical availability findings of 38 individual ICT applications at which they were mathematically measured and complement Table 1 findings. Other two collected sources of technologies and applications spanning from 1996–2016 include two LR articles of [9], [10]. The name discrepancy of the 38 ICT apps necessitated to group the ICT apps into 28 functional groups. Figure 1 depicts the availability penetration levels of the functioanl ICT apps based on the 36 reviewed articles at which the world’s avg penetration level represented 18.63%, while Table 2 demonstrates the 28 groups.

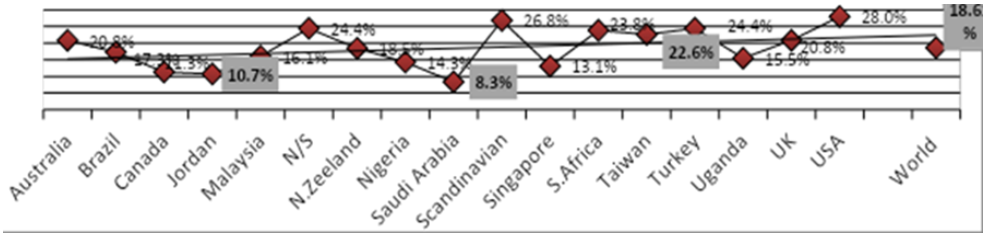

Figure 1. The ICT applications’ penetration in the AEC sector worldwide

Table 1. The ICT applications' penetration in the construction sector worldwide

	Author	Country	Year	Publication title
1	Thomas *et al.*	Australia	2001	Current state of IT usage by Australian subcontractors
2	Stewart *et al.*	Australia	2002	Strategie implementation of IT/IS project in construction: a case study
3	Michaloski and Costa	Brazil	2010	A survey of IT use by small and medium-sized construction companies in a city in Brazil
4	Scheer *et al.*	Brazil	2007	The scenario and trends in the Brazilian IT construction applications' experience
5	Rivard	Canada	2000	A survey on the impact of information technology on the Canadian architecture, engineering and construction sector
6	ElMashaleh	Jordan	2007	Benchmarking information technology utilization in the construction sector in Jordan
7	Derman and Salleh	Malaysia	2010	Literation review on information and communication technology (ICT) system to support integration construction supply chain
8	Lim *et al.*	Malaysia	2002	A survey of internet usage in the Malaysian construcion sector
9	Bjork	NA	1997	INFOMATE: A framework for discussing information technology applications in construction
10	Bjork	NA	1999	Information technology in construction: domain definition and research issues
11	Nourbaksh *et al.*	NA	2012	Mobile application prototype for on-site information management in construction sector
12	Davies	New Zeeland	2010	IT Barometer New Zealand-A survey of computer usage and attitudes in the New Zealand construction sector
13	Doherty	New Zeeland	1997	A survey of computer use in the New Zealand building and construction Sector
14	Wikinson	New Zeeland	2012	An alaysis of the use of information technology for project management in the New Zealand construction sector
15	Oladepo	Nigeria	2007	An investigation into the use of ICT in the Nigerian construction sector
16	O'BRIEN and Biqami	Saudi Arabia	1997	Survey of information technology and the structure of the Saudi Arabian Construction sector
17	Howard *et al.*	Scandinavia	1998	Survey of IT in the construction sector and the experience of IT barometer in Scandinavia
18	Sorensen *et al.*	Scandinavia	2008	Radio frequency identification in construction operation and maintenance-contextual analysis of user needs
19	Samuelson	Scandinavia	2002	IT barometer 2000. The use of IT om the Nordic construction sector
20	Samuelson	Scandinavia	2008	The IT barometer-A decade's development of IT use in the Swedish construction sector
21	Hua	Singapore	2005	IT barometer 2003: Survey of the Singapore construction sector and a comparison of results
22	Arif and Karam	South Africa	2005	Archicetural pratices and IT local vs international
23	Murray *et al.*	South Africa	2001	The intergrated use information and communication technology in the construction sector
24	Ozumba and Shakantu	South Africa	2008	Improving site management process through ICT
25	Chien and Barthorpe	Taiwan	2010	The current state of information and communication technology usage by SME sized Taiwanese construction companies
26	Tan	Taiwan	1996	Information technology and perceived competitive advantage: an empiricial study of engineering consulting firms in Taiwan
27	Irlayici and Tas	Turkey	2008	A role of the usage information technology in Turkish contractor firms
28	Sarshar and Isikdah	Turkey	2004	A survey of ICT uses in the Turkish contractor sector
29	Mutesi and Kyakula	Uganda	2009	Application of ICT in the contractor sector in Kampala
30	Bouchaghem *et al.*	UK	1996	Virtual reality applications in the UK's contractor sector
31	Clark *et al.*	UK	1999	Benchmarking the use of IT to support supplier management in construction
32	Wong and Sloan	UK	2004	Use of ICT for procurement in the UK contractor sector: A survet of SMEs readiness
33	Craig & Sommerville	UK	2006	Information management systems on construction projects: case reviewes
34	EIGhandour	USA	2004	Survey of information technology applications in construction
35	Perkinson and Ahmad	USA	2006	Computing techology usage in construction contractor organizations
36	Tatari *et al.*	USA	2007	Current state of contractor enterprise information systems: survey research

Table 2. ICT percentage increase w.r.t. world's average

G. No	ICT group type	G. No	ICT group type
G01	Modeling software/architectural & engineering design (CADnd, CAM, ACAD, AutoCAD LT, BIM)	G15	Email
G02	CorelDraw, Viso	G16	Internet (WAN)
G03	Engineering Analysis MathCad, Microstran, Pframe), (Turboframe and MathCAD)	G17	Internet (LAN)
G04	Animation/3D	G18	Web portals
G05	3D MaX	G19	Virtual reality
G06	Contouring software (QuickSurf and SurfMate)	G20	Vidio conferencing
G07	Structure analysis: Prokon and Staad/NokiaN73/Earthworks SW (Civil designer-survey and terrain)/Drainage SW (Civil Designer-Storm CAD-Flowmeter-Culvertmaster-Pond Pack)	G21	Project management information systems-Ms Project-Primavera-timeline-superproject
G08	Atmospheric analysis systems/ Structure analysis systems/ Fluid	G22	Project web
G09	Accounting systems (Solution 6)	G23	Mobile technology-for on-site (mobile CAD, data capture, project management applications)-PDA-based collection/construction
G10	Financial management system	G24	Quantity surveying systems
G11	Enterprise resource planning (ERP)/construction ER	G25	Cost estimating software:(CACE)
G12	EDMS (Project Extranet, Project Web, Project Bank, Project Specific Website, DocPool, Porject Information Mgt System)	G26	Human resource management
G13	EDI	G27	E-Bidding
G14	Word, Excel, Access, PowerPoint	G28	E-Tendering

2.3. ISA as an ICT reference model

According to Cloutier *et al.* [11], reference models (RM) are abstract solution patterns to design domain specific systems which provide generic solution patterns and mitigate the complexity of the ICT landscape [12], constitute organization-specific configuration [13], form a representation of a homogeneous group of components including, process, system, or area, and is developed for the analysis, improvement, and/or replacement of the specified process [14], [15]. Also, RMs express "a point of reference for the development of specific models" [16], facilitate cross agency analysis, and identify duplicative ICT investments, gaps, and opportunities [17]. Previous studies on the development of EA based ISA models are scarce in many industries including the AEC sector. In their discussion about ICT reference models, [17] advocated that many architecture descriptions, labelled as a reference model, describe the technical architecture. They compared between five ICT RMs including, performance RM, business RM, service component RM, data RM and technical RM. Not an exception, Gammelgård [18] proposed an EA-based RM software (SW), hardware (HW), and infrastructure, which was aimed to solve decision support difficulties for IT management in EA. Also, Pesic and Aalst [19] identified two types of ICT RMs namely, best practice RMs which elicit domain practices and system oriented RMs that elicit structure of systems. Oppositely, Novotný [20] advocated that RMs are developed by SW developers then they developed a RM that maintains detailed information about a real business enterprise's informatics structure and management.

3. RESEARCH METHOD

DSR is one of the two paradigms that characterize most of the research in information systems discipline aiming at creating new and innovative artifacts [21]. This study is directed by the DSR approach as advocated by [22]. DSR is a six phased methodology which is widely used to solve several enterprises-based issues, including ICT, by constructing and evaluating ICT artifacts. "Problem identification" is the 1st phase to deal with concepts and theories and significance of problem at hand, while "objective definition" is concerned with the research gap as a 2nd phase. "Design and development of the artifact", "demonstration" of the use of analysed artifact, "evaluation", and "communication" of study findings are the following four phases of DSR. Notably, Figure 2 depicts the six phases of current study at which the first two phases of DSR are represented by one of two sub phases named "identification and definition", while the construction phase explains the design and development process of the artifact utilizing the case study approach. Evaluation of the artifact is conducted by utilizing Delphi method while the communication phase comprises the presentation and documentation of the results in the entire paper.

3.1. Problem identification and definition of objectives

Prior to the construction process of the ISA model, an appropriate method for ICT architectural representation of enterprises was employed throughout the identification and tailoring of architectural phases

and core components to describe the baseline (as-is) of ICT elements throughout the alignment with the actual adjacent core elements.

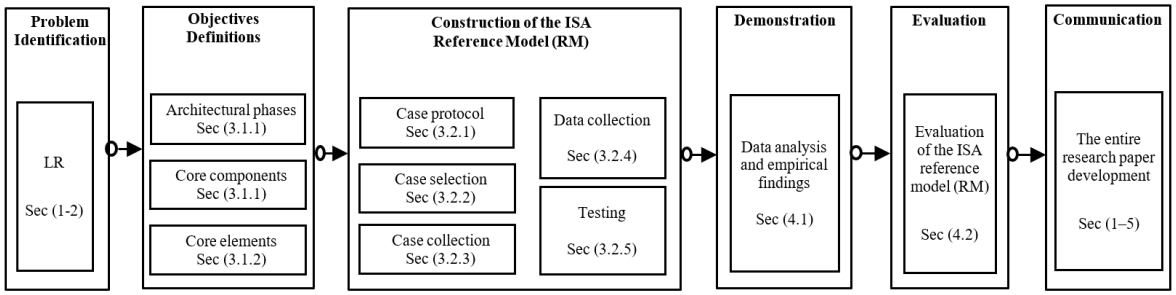

Figure 2. The architectural representation-based phases and processes

3.1.1. The architectural phases and core components

According to The Open Group [13], the ISA (Phase C) is preceded by an architecture vision (phase A) and a business architecture (BA/Phase B). The architecture vision, demonstrated in Appendix 2, is aimed to 1) ensure that the evolution of the architecture development cycle is supported by the management of the enterprise, 2) validate the business principles, goals, and strategic business drivers of the enterprises, 3) define and identify the scope of the components of the BA effort, 4) define the relevant stakeholders and their concerns and objectives, 5) define and articulate the key business requirements, 6) articulate an architecture vision that demonstrates a response to those requirements and constraints, and 7) secure formal approval to proceed. The BA provides a comprehensive overview of an enterprise through the usage of several different architectural views to depict how an enterprise executes business in line with its operating model. The core components of an enterprise represent the holistic multi-dimensional views of business capabilities and ICT capabilities. The former entails views of the strategic objective (SO), organization structure, including, units (U), actor/role, processes (P), functions (F), and services (S). The follower entails several views; ICT baseline applications, portfolio summary, and portfolio details. Figure 3 depicts the initial architectural representation-based ISA model. The key data collected for the ICT baseline applications include app-id, app-name, app-description, vendor, and origin. The key data collected for the ICT portfolio summary include app-id, unit-id, function-id, owner, status, and description, while app-id, function-id, process-id, and service-id, app-type, and primary user, all correspond to the ICT portfolio details.

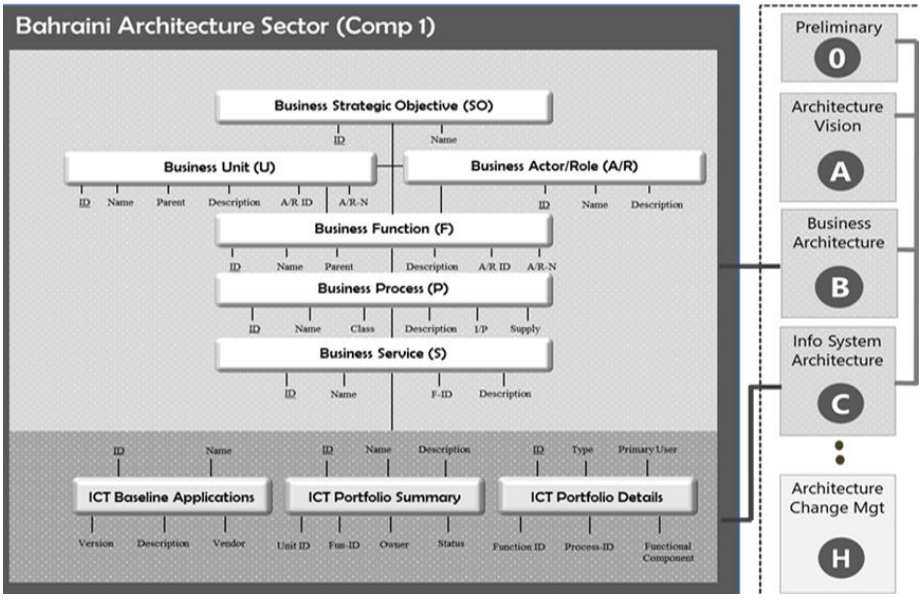

Figure 3. The ISA model views and attributes

3.1.2. Core elements of the ISA model

The ISA core elements correspond to the ISA entities and processes. Based on the literature review findings, a suggested ISA model should encompass business core elements such as, the business strategic mission and vision SO, the business units U, the business stakeholders A/R, the business functions F, the business processes P, and the business services S. However, such elements should first be justified and then mapped to the core components [13]. However, Figure 4 depicts the conceptual model of the actual ISA elements. The model focuses on the ICT applications and/or data considerations that support the BA views of the enterprise, that is, defines the major kinds of ICT application systems (logical groups of capabilities) necessary to process the data and support the business by presenting information to the human and computer actors in the enterprise.

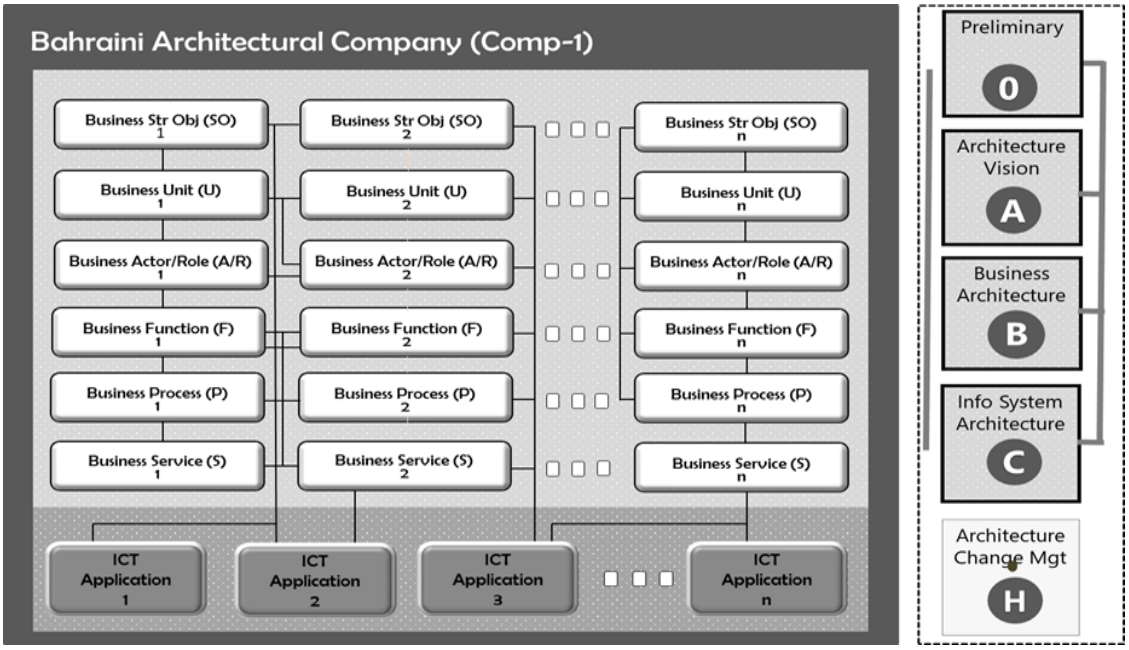

Figure 4. The ISA conceptual model

3.2. Construction of the ISA conceptual model

As a commonly used approach in information systems, this study builds an ISA model from a qualitative case study strategy. For a successful case study design, [23] determined eight steps such as, designing a protocol, determining research questions, performing case selection, identifying data collection and analysis techniques, collecting data, evaluating and analyzing data, and writing the report. Therefore, a single, exploratory, descriptive, and in-depth case study was found reasonable to the problem at hand.

3.2.1. Case study protocol

Based on the insights of Yin [23], Table 3 demonstrates the seven sections of case study protocol design, while Appendix 4 ellaborates on the protocol document for the case study. The document is composed of seven sections matrix. Respectively, the sections include an overview, field procedures, research questions, data collection matrix, architectural vision template (I), BA template (II) and ISA template (III).

Table 3. The protocol design of the case study

Section No.	Topic	Content
1	Overview	A statement of the overall aims of the research
2	Field procedures	How to gain access, capture data, and time plan for data colletion. for each case.
3	Research questions	Specific research questions stated with clear links to the theory/literature.
4	Data collection matrix	A matrix (table) for collected evidence, corresponding to the research questions.
5	Template (I)	Architectural vision document templates
6	Template (II)	Business architecture document templates
7	Template (III)	Information systems architecture document templates

3.2.2. Case selection

The selected case study is a single precautionary and exploratory version that is activated prior to a larger main study [23] determine 16 purposes for a such a case study of which the current single case study tests the appropriateness of the research instruments, including the research protocol, the formulated research questions and the subsequent research plan. Considering the insights of [23], [24], comp01 was found best matching the predetermined criterions as the "criterion case" because it is located in Bahrain, A-grade having standardized business functions and work processes, fast responsive to the interview request. comp01 was founded in 1990 of 35 personnel, provided AEC services, was A-grade licensed. comp01 is an international architectural engineering office, located in Manama, Bahrain, founded in 2002 and grants a grade-A Engineering practicing licence from the Bahraini committee for organizing engineering professional practice (COEPP).

3.2.3. Research questions formulation

Measuring the penetration levels of ICT applications necessitates answering one main question and seven sub-questions as demonstrated in section 3 of Appendix 4. The main question was about identifying the supporting ICT applications of the Bahraini AEC enterprise w.r.t the business views of comp01. Q1.1–Q1.5 were meant to inform the domestic and worldwide measurement of the ICT applications penetration, while Q1.6 was aimed to provide an enterprise modeling representation, that is, to graphically express the interelationships of ICT applications. Q1.7 provided statistical measures to the comparative penetration level (%) of comp01 ICT applications to the world (i.e., the average measured for the 17 countries).

3.2.4. Data collection of core elements

Based on the formulated questions, the structured interviews and document analysis were respectively the two performed primary and secondary qualitative data collection techniques in this study. Th triangulation was addressed to gain in rich data, to ensure rigorousness, to overcome the potential bias, and to satisfy validity and reliability factors of the study [25]. Based on the recommendations of [26], the sample size was determined based on who recommends three to five interviewees per case study. Three personal interviews (i.e., face-to-face and telephone calls) were employed, each of which ranged between 2-3 hours along with 3 phone call conversations of 10-15 minutes each. The interviewees consisted of the chief architect, the managing director, the deputy general manager, a group of architects & draftsmen, and IT manager. Performing document analysis required analysing the business case web pages, presentations, brochures, strategic plan, and architecture projects along with the analysis of the ICT application manuals and vendor specification sheets. The collected datasets were manually coded according to the matrix predetermined themes (template I, II, III) in MS excel. Thematic analysis was conducted following the suggestions of [27].

3.2.5. Testing of the case study design

Three tests (i.e., construct validity, external validity, and reliability) were performed to measure the quality during the phases of the case study [23]. For the external validity test during research design and data collection stages, the necessity to perfrom this study was drawn from the substancial lack of previous stuides on the problem at hand. Recall that selecting comp01 was based on several criterions (i.e., A-Grade, located in Bahrain, having standard business and ICT functions and work processes, and fast responsive to interview request. Since the moment it was requested to participate in the interviews, com01 was the most welcoming enterprise to get involved having their staff members available during the day time to answer face-face and phone call questions. Research quality was a concern. Honesty was not questionable as the staff never faked any piece of data. On contrary, they provided precise organizational structure, invoices and documentary written materials. Also, during the data collection stage, a case study protocol was developed including research objectives and questions, field procedures, details of all types of evidence besides the structure of the final research, and a report writing that identified the audience, determined the best structure, and organization of the written report. Moreover, construct validity for data collection and composition stages was claimed by establishing precise operational measures for the study concepts by corresponding the data collection questions and measures to the research questions and propositions, through using a chain of evidence (Triangulation). Two primary sources of evidence included face-face interview and a non-standardized interview by telephone along with two secondary sources including, organizational structure and website documentary written material. A revision was conducted to the draft case study report during the composition stage and in the middle and the end of the collection procedure. Reliability during the data collection stage was claimed through developing a repository (i.e., business architecture templates) to the case study to document the data collection procedures and finding. Thus, collected interviews findings,

memos and notes were transcribed, organized, and protected as per the request of the enterprise, at which the enterprise name was replaced by a code no. Also, an electronic filing database was established to store a back up to the transcripts at various stages in the process.

4. RESULTS AND DISCUSSION

4.1. Demonstration

The analysis work draws on the four based steps of analysis method framework that classifies and organizes the datasets into themes, categories, and concepts in order to identify similarities and differences between participants [27]. The analysis, for both the business and ICT apps sides, worked as follows: First, data coding index was assigned to each identified concept during the interviews, in the format of A.0.0.0.0. Subheadings were assigned to the concepts under each heading in the form of A.1.0, 0.0. The concept is indexed in the format of A.0.1.0.0 with sub-concepts assigned as A.0.2.0.0. Numerical codes were recorded in the transcripts. Second, resulting data was sorted to gather similar content text. Third, categorized data was examined to determine the range of the content within the theme. Fourth, each theme was developed on a thematic chart.

4.1.1. The ICT applications strategic objectives

This section answers the first question of the study at which the ICT applications and baseline functionalities were not deployed as comp01 has not set ICT SO yet.

4.1.2. The ICT applications corresponding to units and actors (U&A/R)

This section answers the second question of the study at which the ICT applications and baseline functionalities were deployed. Table 4 demonstrates 15 baseline ICT applications, for example, Auto computer-aided design (AutoCAD) (App01), is a two-dimensional (2D) and three-dimensional (3D) modelling and design application that is developed and marketed by Autodesk in USA. Furthermore, Table 5 lists the corresponding ICT applications w.r.t the business units and actors/roles.

Table 4. ICT baseline applications

App-id	App name	App description	Vendor	Origin
App01	AutoCAD	2D and 3D computer-aided design and drafting.	Autodesk	USA
App02	3d Max	A 3D animation, modelling, and rendering software.	Autodesk	USA
App03	V-Rav	Rendering plugin software for 3D computer graphics applications.	V rav	Bulgaria
App04	Adobe Photoshop	Raster graphics editing software.	Adobe Sys	USA
App05	Adobe Acrobat	Used to share and archive drawings, specifications and project info.	Adobe	USA
App06	STAAD/Pro	Used for analysis and desingns of structures: buildings and bridges.	Bentley Systems	USA
App07	Orion	2D/3D structural analysis, design, drawings s/w.	Trimble	Finland
App08	Tally ERP	Records and classifies the financial transcions.	Tally Solutions	India
App09	Ms Office	Report writing & spreadsheets.	Microsoft	USA
App10	Windows 2008	Server OS.	Microsoft	USA
App11	Symantec Backup	Makes copies of physical storage environments for disaster recovery.	Microsoft	USA
App12	Kaspersky	Antivirus and online security program.	Kaspersky	Russia
App13	Trend Micro	Antivirus and online security program.	Trend	USA
App14	Internet	Internet service.	Microsoft	USA
App15	Email	External mail application.	Microsoft	USA

Table 5. ICT applications w.r.t units & actor/role

App-id	App name	Unit id	Unit name	Unit parent	Actor id	Actor/Role
App01	AutoCAD	U01	Proprietor or director	Management	A/R 01	Proprietor&director
App02	3d Max	U02	G. deputy management	Management	A/R 02	General deputy manager
App03	V-Rav	U03	Chief architecture	Architecting	A/R 03	Chief architect
App04	Adobe Photoshop	U04	Senior/junior architecture	Architecting	A/R 04	Senior/Junior architect
App05	Adobe Acrobat	U05	Drafting	Engineering	A/R 05	Draftsman
App06	STAAD/Pro	U06	Structural engineering	Engineering	A/R 06	Structural engineer
App07	Orion	U07	Mechanical engineering	Engineering	A/R 07	Mechanical engineer
App08	Tally ERP	U08	Electrical engineering	Engineering	A/R 08	Electrical engineer
App09	Ms Office	U09	Quantity surveing	Q. surveying	A/R 09	Quantity surveyor
App10	Windows 2008	U10	Tendering &contracting	Tender & contract	A/R 10	Plumber
App11	Symantec Backup	U11	Municipal liaison	Tendering & contract	A/R 11	Municipal liaison officer
App12	Kaspersky antivirus	U12	Project site engineering	Supervision	A/R 12	Project site engineer
App13	Trend Micro antivirus	U13	Accounting & finance	Supporting	A/R 13	Accounting manager
App14	Internet	U14	HR & administration	Supporting	A/R 14	HR & admin manager
App15	Email	U15	IT	Supporting	A/R 15	General deputy manager

4.1.3. The ICT applications corresponding to functions (F)

This section answers the third question of the study at which the ICT applications and baseline functionalities were deployed. Through traceability, 15 ICT applications were distributed w.r.t the function. Table 6 explores the ICT portfolio summary at which 3dMax (App02), for example, is owned and used by senior/junior architect actor (A/R04) in senior architecture unit (U04) to perform architecting function (F02).

Table 6. ICT applications w.r.t functions

App-id	Function id	Function name	Function id	Owner (actors/roles)
App01	F2, F3	Architecting, engineering	U4, U5, U6, U7, U8, U9	A/R4, A/R5, A/R6, A/R7, A/R8, A/R9
App02	F2	Architecting	U4	A/R4
App03	F2	Architecting	U4	A/R4
App04	F2	Architecting	U4	A/R4
App05	F1, F4	Managing, tendering & contract	U3, U11	A/R3, A/R11
App06	F3	Engineering	U4, U6, U9	A/R4, A/R6, A/R9
App07	F3	Engineering	U6	A/R6
App08	F6	Supporting	U13	A/R13
App09	F1, F2, F3, F4, F5, F6	Managing-… Supporting	U1, U2, U6, U7, U9, U10, U13	A/R1, A/R2, A/R6, A/R7, A/R9, A/R10, A/R13
App10	F1	Managing	U1	A/R1
App11	F1	Managing	U1	A/R1
App12	F1	Managing	U1	A/R1
App13	F1	Managing	U1	A/R1
App14	F1, F2, F3, F4, F5, F6	Managing-… Supporting	U1-U15	A/R1-A/R15
App15	F1, F2, F3, F4, F5, F6	Managing-… Supporting	U1-U15	A/R1-A/R15

4.1.4. The ICT applications corresponding to processes (P)

This section answers the fourth question of the study at which the ICT applications and baseline functionalities were deployed. Through traceability, 15 ICT applications were deployed. Table 7 explores the distribution of the ICT applications w.r.t. process view. Thus, Trend Micro antivirus (App13), for example, is used to secure the scope of work process (P01) that is set by proprietor& managing director actor (A/R01) who is working in management unit (U01) to perform management (F01).

Table 7. ICT applications w.r.t processes

App-id	Process-id	App-type	Function id	Owner (Actors/Roles
App01	P3, P4, P5, P7	COTS	F2, F3	Svc2
App02	P5	COTS	F2	Svc2
App03	P5	COTS	F2	Svc2
App04	P5	COTS	F2	Svc2
App05	P5, P6, P7	COTS	F1, F4	Svc2, Svc3
App06	P5	COTS	F3	Svc2
App07	P5, P7	COTS	F3	Svc2
App08	P5, P6, P7, P8, P9	COTS	F6	Svc4
App09	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10	COTS	F1, F2, F3, F4, F5, F6	Svc1, Svc2, Svc3, Svc4
App10	P3	COTS	F1	Svc1
App11	P3	COTS	F1	Svc1
App12	P3	COTS	F1	Svc1
App13	P3	COTS	F1	Svc1
App14	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10	COTS	F1, F2, F3, F4, F5, F6	Svc1, Svc2, Svc3, Svc4
App15	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10	COTS	F1, F2, F3, F4, F5, F6	Svc1, Svc2, Svc3, Svc4

4.1.5. The ICT applications corresponding to services (svc)

This section answers the fifth question of the study at which the ICT applications and baseline functionalities were deployed. Apparently, 15 individual ICT applicappeations were deployed. Table 8 explores the distribution of the ICT applications w.r.t. services. Tally ERP (App08) is an accounting and finance application that is executed by an accounting manager actor (A/R13) and is exploited in accounting and finance unit (U13) which performs supporting function (F06) to provide supervision, management&completion (Svc04) to clients.

Table 8. ICT applications w.r.t services

App-id	Service id	Unit id	Actor/Role id	Function id
App01	Svc2	U4, U5, U6, U7, U8, U9	A/R4, A/R5, A/R6, A/R7, A/R8, A/R9	F02, F3
App02	Svc2	U4	A/R4	F2
App03	Svc3	U4	A/R4	F2
App04	Svc2	U4	A/R4	F2
App05	Svc2, Svc3	U3, U11	A/R3, A/R11	F2, F4
App06	Svc2	U4, U6, U9	A/R4, A/R6, A/R9	F3
App07	Svc2	U6	A/R6	F3
App08	Svc4	U13	A/R13	F6
App09	Svc1	U1, U2, U6, U7, U9, U10, U13	A/R1, A/R2, A/R6, A/R7, A/R9, A/R10, A/R13	F1, F2, F3, F4, F5, F6
App10	Svc1	U1	A/R1	F1
App11	Svc1	U1	A/R1	F1
App12	Svc1	U1	A/R1	F1
App13	Svc1	U1	A/R1	F1
App14	Svc1	U1-U15	A/R1-A/R15	F1, F2, F3, F4, F5, F6
App15	Svc1, Svc2, Svc3, Svc4	U1-U15	A/R1-A/R15	F1, F2, F3, F4, F5, F6

4.1.6. The graphical representation of relationships

This section answers the sixth question of the study. Figure 5 depicts the penetration of the ICT applications within the business elements; unit & actor/role, function, process, and service.

	F01		F02		F03					F04		F05	F06		
	U01	U02	U03	U04	U05	U06	U07	U08	U09	U10	U11	U12	U13	U14	U15
P01	9,14,15	9,14,15	14,15	14,15	14,15	9,14,15	9,14,15	14,15	9,14,15	9,14,15	14,15	14,15	14,15	14,15	14,15
P02	9,14,15	9,14,15	14,15	14,15	14,15	9,14,15	9,14,15	14,15	9,14,15	9,14,15	14,15	14,15	14,15	14,15	14,15
P03	9,10,11,12,13,14,15	9,14,15	14,15	1,14,15	1,14,15	1,9,14,15	1,9,14,15	1,14,15	1,9,14,15	9,14,15	14,15	14,15	14,15	14,15	14,15
P04	9,14,15	9,14,15	14,15	1,14,15	1,14,15	1,9,14,15	1,9,14,15	1,14,15	1,9,14,15	9,14,15	14,15	14,15	14,15	14,15	14,15
P05	9,14,15	9,14,15	5,14,15	1,2,3,4,6,14,15	1,14,15	1,6,7,9,14,15	1,9,14,15	1,14,15	1,6,9,14,15	9,14,15	5	14,15	8	14,15	14,15
P06	9,14,15	9,14,15	5,14,15	14,15	14,15	9	9,14,15	14,15	9,14,15	9,14,15	5	14,15	8	14,15	14,15
P07	9,14,15	9,14,15	5,14,15	1,14,15	1,14,15	1,7,9,14,15	1,9,14,15	1,14,15	1,9,14,15	9,14,15	5	14,15	8	14,15	14,15
P08	9,14,15	9,14,15	5,14,15	14,15	14,15	9	9,14,15	14,15	9,14,15	9,14,15	14,15	14,15	8	14,15	14,15
P09	9,14,15	9,14,15	5,14,15	14,15	14,15	9,14,15	9,14,15	14,15	9,14,15	9,14,15	14,15	14,15	14,15	14,15	14,15
P10	9,14,15	9,14,15	5,14,15	14,15	14,15	9,14,15	9,14,15	14,15	9,14,15	9,14,15	14,15	14,15	14,15	14,15	14,15
	Svc01		Svc02							Svc03		Svc04			

Figure 5. Penetration of the ICT applications within the business elements

4.1.7. Benchmark of ICT penetration level

This section answers the seventh question of the study. Measuring the penetration level (%) of individual ICT applications for com01 was performed as follows. For *P=penetration; x=No of rows; y=No of columns; N=0/1* where P_x refers to the application order in the table, $P_1 = App1$, $P_2 = App16$, $P_3 = App17$, ..., $P_{38} = App10$

$$P_{S,x}\% \frac{\left(\sum_{y=1}^{4} N_{x,y}\right)}{4} x\ 100\% \quad (1)$$

$$\textbf{ICT penetration (\%) of each application w.r.t service} = \frac{Sum\ of\ availability\ of\ servise\ of\ each\ application}{Total\ number\ of\ services} x\ 100\%$$

$$P_{F,x}\% \frac{\left(\sum_{y=1}^{6} N_{x,y}\right)}{6} x\ 100\% \quad (2)$$

$$\textbf{ICT penetration (\%) of each application w.r.t function} = \frac{Sum\ of\ availability\ of\ fuction\ of\ each\ application}{Total\ number\ of\ functions} x\ 100\%$$

$$P_{P,x}\% \frac{(\sum_{y=1}^{10} N_{x,y})}{10} x\ 100\% \quad (3)$$

ICT penetration (%) **of each application w. r. t process** $= \frac{Sum\ of\ availability\ of\ process\ of\ each\ application}{Total\ number\ of\ processes} x\ 100\%$

$$P_x\% \frac{(\sum_{y=1}^{20} N_{x,y})}{20} x\ 100\% \quad (4)$$

ICT penetration (%) **of each application** $= \frac{\text{Sum of availability of service, function, \& process of each application}}{\text{Total number of service, function, \& process}} x\ 100\%$

$$App\% \frac{(\sum_{x=1}^{No} P_x)}{20} x\ 100\% \quad (5)$$

ICT penetration of all applications in each company (%) $= \frac{\text{Sum of percentages of each company}}{\text{Number of applications in each company}}$

$$P_x\% \frac{(\sum_{y=1}^{6} N_{x,y})}{6} x\ 100\% \quad (6)$$

ICT penetration of each application (%) $= \frac{\text{Sum of availability of companies}}{\text{Total number of companies}} x\ 100\%$

$$C_y\% \frac{(\sum_{x=1}^{38} N_{x,y})}{38} x\ 100\% \quad (7)$$

ICT penetration of each company (%) $= \frac{\text{Sum of availability of applications}}{\text{Total number of applications}} x\ 100\%$

$$G_M\% \frac{\left(\sum_{x=1}^{x=38} \sum_{y=1}^{y=11} N_{x,y}\right)}{38} x\ 100\% \quad (8)$$

ICT penetration of each group (%) $= \frac{\text{Sum of availability of applications in each group}}{\text{Total number of applications}} x\ 100\%$

However, the formulas (6-8) illustrate the measurement results of individual/group of ICT applications penetration levels of the entire Bahraini sector as follows: For x=number of rows; y=number of columns; N=(0 or 1); M=A, B, ..., K; P_x=the application order as appears in the table. Resulting from the formulas, Figure 6 demonstrates the scoring of 47.4% w.r.t. functions, 42.3% w.r.t processes, 51.9% w.r.t services, and an overall score of 49.7%.

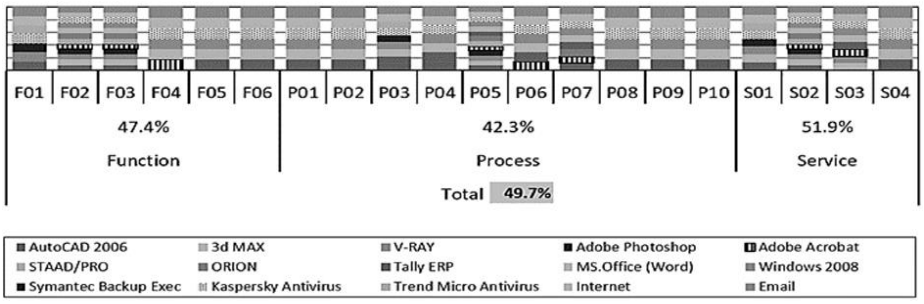

Figure 6. ICT application penetration levels

Recall from section 2 that by the meta-analysis technique, the study determined the presence of 38 individual ICT applications of the construction industry in 17 countries. Compared to the world's avg penetration, Table 9 depicts the penetration levels of the 28 groups of ICT apps of comp01 w.r.t. functions, while processes and services were excluded due to the unavailability of a worldwide BA model for the AEC sector. As a representative of the Bahraini AEC sector, comp01 scored 18.5% against Saudi Arabia of 8.3%, Jordan of 10.7%, Turkey of 22.6%, and below the worldwide average by 0.1%.

Table 9. ICT applications penetration levels of comp01

		F01	F02	F03	F04	F05	F06	
Applications	1	0	1	1	0	0	0	
	2	0	0	0	0	0	0	
	3	0	0	0	0	0	0	
	4	0	1	1	0	0	0	
	5	0	1	1	0	0	0	
	6	0	0	0	0	0	0	
	7	0	1	1	0	0	0	
	8	0	1	1	0	0	0	
	9	0	0	0	0	0	1	
	10	0	0	0	0	0	1	
	11	0	0	0	0	0	0	
	12	0	0	0	0	0	0	
	13	0	0	0	0	0	0	
	14	1	1	1	1	1	1	
	15	1	1	1	1	1	1	
	16	1	1	1	1	1	1	
	17	0	0	0	0	0	0	
	18	0	0	0	0	0	0	
	19	0	0	0	0	0	0	
	20	0	0	0	0	0	0	
	21	0	0	0	0	0	0	
	22	0	0	0	0	0	0	
	23	0	0	0	0	0	0	
	24	0	0	0	0	0	0	
	25	0	0	0	0	0	0	
	26	0	0	0	0	0	0	
	27	0	0	0	0	0	0	
	28	0	0	0	0	0	0	Avg (%)
		14.30%	28.60%	28.60%	10.70%	10.70%	17.9	18.50%

4.2. Evaluation and communication

Two criterions oblige the evaluation of developed model, theoretical soundness, and the modelling taxonomy. Through several rounds, Delphi technique was applied to collect experts' opinions on specific questions and produce quality argument about the constructed model. Habibi *et al.* [28] suggest at least two rounds for the feedback collection. According to Iden *et al.* [29], the selection of the expert panel and the number of rounds form the success factors of Delphi technique. Consequently, 2 rounds were set for the evaluation while 4 experts were selected from the Bahraini information & e-government authority and the Comp1 to evaluate the ISA model design and the benchmark of ICT application efforts based on 11 parameters/criterions. The comments were then collected, grouped, synthesized until the final model development [30]. The quality criterions under which the ISA model was evaluated in 2 rounds based on a 5-point likert scale (S.Agree=5–S.Disagree=1) questionnaire as listed in Table 10, all along with the average values to achieve an a 64% of ISA RM appropriateness.

Table 10. The evaluation findings of the ISA RM

Criterions	Description	Round 1 (%)					Round 2 (%)					Total rounds avg (%)				
		S.Ag	Agree	Neut	D.A	SDis	S.Ag	Agree	Neut	D.A	SDis	S.Ag	Ag	Neut	D.A	SDis
Clarity	Easily understandable	100	0	0	0	0	100	0	0	0	0	100	0	0	0	0
Simplicity	Quickly understandable	100	0	0	0	0	100	0	0	0	0	100	0	0	0	0
Expressiveness	Describes reality thoroughly	25	75	0	0	0	25	50	25	0	0	25	63	13	0	0
Minimality	Contain no redundant concepts	0	0	50	50	0	25	0	50	25	0	13	0	50	38	0
Completeness	Describes particular app domain	0	100	0	0	0	75	25	0	0	0	38	63	0	0	0
Accuracy	Complied to reality	25	75	0	0	0	0	75	25	0	0	13	75	13	0	0
Abstraction	Provides highly abstract concept	25	25	50	0	0	25	25	50	0	0	25	25	50	0	0
Consistency	Provides standardized diagrams	0	50	50	0	0	0	75	25	0	0	0	63	38	0	0
Unambiguity	Provides clear linking to units	50	0	50	0	0	50	0	50	0	0	50	0	50	0	0
Testability	Provides testable hypothesis	25	25	50	0	0	50	0	50	0	0	38	13	50	0	0
Reproducibility	Provides computerized analysis	0	0	25	75	0	0	0	100	0	0	0	0	63	38	0
	Average	32	32	25	11	0	41	23	34	2	0	36	27	30	7	0

Communication refers to the importance and effectiveness of the artifact to the researcher at which the identified problem and the proposed solution should be documented for publication excluding any restricted or sensitive information of the enterprise. All aspects of the problem and the designed artifact arecommunicated to the relevant stakeholders and academic audience throughout this paper publication.

5. CONCLUSION

In order to benchmark the ICT applications' penetration levels of the Bahraini AEC's sector, this study analysed 36 article representing 17 countries, benchmarked 38 individual (28 groups) applications, constructed a representative ISA RM to the Bahraini sector, and conducted an exploratory Case study to act as startup case to evaluate the appropriateness of the research instruments for conducting a potential multiple case study, design the adequacy of a research protocol, determine resources, and formulate research questions. The benchmark is based on the construction of ISA RM from a Bahraini AEC enterprise and the evaluation reveals 64% appropriatness.

APPENDIX

Appendix 1-The business architecture (BA)

a. The business units of comp01

Unit id	Unit name	Unit parent	Description
U01	Proprietor or managing director	Management	Setting the tone for enterprise's management and operations
U02	General deputy management	Management	Running of enterprise's management and operations
U03	Chief architecture	Architecting	Designing focusing on all project activities
U04	Senior/junior architecture	Architecting	Design focus of specific project activities
U05	Drafting	Engineering	Sktching detailed technical drawings for buidings by a software
U06	Structural engineering	Engineering	Performing of stability and strength of built structure for buildings
U07	Mechanical engineering	Engineering	Performing HVAC, piping, and water supply
U08	Electrical engineering	Engineering	Surveying the site and managing the design of electrical systems
U09	Quantity surveing	Quantity surveying	Performing construction costs and contracts
U10	Tendering	Tendering & contract	Working through tender process and const & maintenance contracts
U11	Municipal liaison	Tendering & contract	A mediation process between the office and the municipality
U12	Project site engineering	Supervision	Setting out the works in accordance with drawings and specification
U13	Accounting & finance	Supporting	Control of enterprise's financial operations and employee relations
U14	HR & administration	Supporting	Management of human resources within the organization
U15	IT	Supporting (virtual)	Instalation, execution, upgrading, and maintenance of software apps

b. The business actors/roles of comp01

Actor id	Actor/Role	Description
A/R 01	Proprietor or Managing Director	An owner/CEO who set the tone for enerprise's management and operations
A/R 02	General Deputy Management	An executive person acting in emergency of the CEO unavailabilty
A/R 03	Chief Architect	A senior licensed architect having a design focus of all project activities
A/R 04	Senior/junior architect	A licensed/non licensed architect having a design focus of specific project activities
A/R 05	Draftsman	A person making detailed technical drawings for buildings by utilizing S/W sketches
A/R 06	Structural engineer	A trained engineer who calculates the stability and strength of built structures for buildings
A/R 07	Mechanical engineer	A specialist in HVAC, piping, and water supply besides acting in middle of other disciplines
A/R 08	Electrical engineer	A person who designs high voltage equipment (wiring systems, lighting systems & generators)
A/R 09	Quantity surveyor	A person having an expertise in construction costs and conracts
A/R 10	Plumber	A person who coordinates plumbing systems in construction projects
A/R 11	Municipal liaison officier	A mediator between the architecture office and the municipality
A/R 12	Project site engineer	A person who perfoms technical, organizational, and supervisory role on construction projects
A/R 13	Accounting Manager	A person who supervises and controls enterprise's financial operations and employee relations
A/R 14	HR & admin Manager	A person who performs time keeping, recruitment, records maintenance, and administration
A/R 15	General Deputy Manager	An executive person acting in emergency of the CEO unavailability

c. The business functions of comp01

Process id	Process name	Description
P01	Scope of work	Client and architect define general description of the work, WBS and scope of services
P02	Agreement	Client & architect estimate cost and write agreement
P03	Conceptual design	Prepare site plan
P04	Schematic design	Develop of master plan
P05	Design development	Develop drawings for building permit, Prelim structruralcalc, design of M.E.P and load calculations
P06	Application of building permit	Drawings upload to municipality and preparation of invoice
P07	Detailed design development	Develop complete construction drawings and invoice
P08	Tender documents preparation	Seek tenders (offers) and design drawings and specifications
P09	Tender & contract awarding	Analysis of Tender documents and Selection of contractors baser on BOQ and schedule
P10	Project site supervision, mgt	Planning, monitoring, project controlling, quality control and contract administration.

d. The business processes of comp01

Func id	Function name	Description
P01	Managing	Budget administration, decision making & meeting with onsultants, clients, engineers
P02	Architecting	Designing of building & working with clients to set (objectives, budget & requirements)
P03	Engineering	Preforming MEP and quantity surveying roles of construction projects
P04	Tendering & conract award	Preforming tendering and award biddings
P05	Supervising	Supervision of construction projects
P06	Supporting	Accounting & finance, HR & administration, and IT related tasks.

The business services of comp01

Svc id	Service name	Description
Svc01	Project planning	Strategic definition and preparation and brief
Svc02	Architectural design provision	Concept, schematic, design development, apply of building permit and detailed design
Svc03	Tendering & conract admin	Tender doc preparation & contract warding
Svc04	Project management, supervision	Project site management & project hand over

Appendix 2-The architecture vision document

	Steps	Tasks Performed
1	Establish the architecture project	Enterprise-Specific Procedures: Explained in Section 2 of Appendix (5)
2	Identify stakeholders, concerns, and business requirenments	a. Stakeholders: Based on the formal structure of comp01, the list of stakeholders included the Cief architect, the Managing director, the Deputy general manager, Architects and Draftsme. Also, the deputy general manager acting as an IT specialist. b. Stakeholder Concerns, Issues, and Cultural factors of the architecture: There were no particular concerns and/or cultural factors that affect the BA. There were no particular concerns and/or cultural factors that affect the BA. c. Key business requirements to be addressed in the architecture engagement: There were no particular requirements that affect the BA. There were no particular requirements that affect the ISA.
3	Confirm and elaborate business goals, business drivers, and constraints	d. Business Goals and Strategic drivers of the organization: Be a full private enterprise so it gets rid of any governmental bureaucracy. Seek quality service aside from any official restrictions. e. Business Constrains of the prganization: Service Private sector, Target the upper-market segment, Customer' full payment at beginning. Recruit less no. of highly qualified staff, has no documented ICT strategy.
4	Evaluate business capabilities	f. What baseline capabilities will be needed to fulfil the business goals and drivers: Managing, Architecting, Engineering: (Drafting, Structure, MEP, Quantity Surveying), Tendering & Contract Award, Supervision, and Supporting
5	Assess readiness for business transformation	g. Perform Business Transformation Readiness Assessment: We don't intened to evaluate the organization's readiness to undergo a charge,
6	Define scope	h. Define what is inside and what is outside the scope of the Baseline architecture: – Target scope is excluded. – Functions, Units, Actors/Roles, Processes and Services are all included. – Cultural considerations are excluded. – The Vision and Bussines architecture are the two included architecture domains
7	Confirm and elaboratr architecture principles, including	Confirmed.

Appendix 3-The worldwide ICT applications in EAC sector

No.	ICT Application	Australia	Brazil	Canada	Jordan	Malaysia	Not Specified	N.Zeeland	Nigeria	KSA	Scandinavia	Singapore	S.Africa	Taiwan	Turkey	Uganda	UK	USA
1	Accounting management information systems and Solution 6										x		x	x			x	x
2	EDMS (Project extranet, Project web, Project bank, Project Website, DocPool, Project information mgt Sys and Virtual)		x		x	x	x			x		x	x	x	x	x		x
3	Computer-aided production management (CAPM)		x		x	x	x			x		x	x	x	x	x		x
4	Enterprise Resource Planning (ERP)/Construction ER					x									x			x
5	GIS (R2V, Trimble GPS)					x							x	x				x
6	Cost estimating Software: (CACE)	x												x	x			
7	Financial Management	x									x		x	x			x	
8	Human Resource Management		x											x				
9	Animation/3D		x											x				x
10	Contouring Software (QuickSurf and SurfMate)		x										x					
11	Modeling SW/architectural& engineering design (CADnD, CAM, ACAD, AutoCAD LT,BIM, Coreldraw,Visio,3DMax)	x	x	x			x	x	x		x	x	x	x	x	x	x	x
12	Quantity surveying systems	x	x	x			x	x						x			x	
13	Supply Chain Management system	x			x			x	x		x			x	x	x		
14	Project Management Information Systems -MS Project-Primavera-Timeline- Superproject	x			x			x			x		x					
15	Project Web	x			x			x				x	x					
16	Word, Excel, Access, PowerPoint	x					x	x	x		x		x		x	x		x
17	Engineering Analysis Math Cad, Microstran, Pframe) , (Turboframe and MathCAD)	x					x	x										
18	Remotely hosted applications and software										x			x			x	
19	Online ordering of products/services from suppliers											x			x		x	
20	Order Processing Systems (EDP)			x														
21	Customized Software (Rental administration for real estate- maintenance for real estate)						x											
22	Order Processing Systems (EDP)						x											
23	Remote software						x				x							
24	Structure anal/ Prokon & Staad/NokiaN73/Earthworks/ Drainage (StormCAD-Flowmaster-Culvertmaster-PondPak		x				x						x					
25	Atmosphere analysis sys-Structure analysis sys-Fluid analysis sys-General and support sys-Network sys-multimedia)		x				x						x		x			
26	Email	x	x	x	x	x	x	x	x	x	x	x			x			
27	Internet (WAN)	x	x	x	x		x	x	x	x	x		x		x	x		
28	Intranet (LAN)														x	x		
29	E-commerce					x												
30	Virtual Reality										x			x				x
31	Radio Frequency (RFID)					x							x					
32	E-Business					x												
33	E-Bidding					x												
34	E-Procurement/Procurement systems					x								x			x	
35	E-Tendering					x								x				
36	Web Portals					x	x				x							
37	Mobile Technology (mobile CAD, data capture, project management applications)-PDA-based collection/Construction					x	x				x							
38	Video Conferencing																	x

Appendix 4–The protocol document

Sec	Topic	Content
1	Overview	This research aims to collect ICT Application's corresponding data of the selected AEC (comp01).
2	Field procedures	1. Selecting an Architectural enterprise (AEC, Grade (A), Welcoming. 2. Requesting for a first visit // by phone calls and emails. 3. Meeting with a representative to explain our research parameters.
3	Research questions	Q1. What are the ICT applications supporting the Bahraini AEC? Q1.1 What are the ICT SO supporting the comp01? Q1.2 What are the ICT applications supporting the Units & Actors/Roles? Q1.3 What are the ICT applications supporting the Functions? Q1.4 What are the ICT applications supporting the Processes? Q1.5 What are the ICT applications supporting the Services? Q1.6 How to graphically express the relationships? Q1.7 What is the comparable ICT applications penetration level of comp01 to the world?
4	Data collection matrix	Q # / Research questions / Evidence (tools) / Data collection technique 1 What are the ICT apps supporting the Bahraini AEC 1.1 What is the ICT S.Obj supporting the comp01? — Temp II (A), Apped(2) 1.2 What are ICT apps supporting the Unit & Actors? — Temp II (B), Temp III 1.3 What are the ICT apps supporting the Functions? — Temp II (C), Temp III 1.4 What are the ICT apps supporting the Processes? — Temp II (F), Temp III 1.5 What are the ICT apps supporting the Services? — Temp II (E), Temp III 1.6 How to graphically express the relationships? 1.7 What is comparable penetration level to the world? — Appendix 1, Appedix 3 Data collection technique: Primary Sources: 1) Face-face interview Qs. 2) Telephone interview. Secondary Sources: 1) Literature Review 2) Documentary (structure, app) 3) Websites materials
5	Template (I)	A. Enterprise details table Ent_id: comp01 / Name: - / Date of collection: Month, Year / Interview positions: CEO/owner, Architects, Civil engineers, PMs / Interviewer: -

Appendix 4–The protocol document (*Continued*)

Sec	Topic	Content
6	Template (II)	A. Organizational SO Business Obj_id: BSO 01 — Business objectives — IT objectives id: ITSO 01 — IT objectives B. Organizational structure and units Unit _id: U01 — Unit name — U_Parent — Unit description — Actor/Role ID — Actor/Role C. Business functions Unit id: U01 — Fun_id: F01 — Fun_Name — Fun_Description — Fun_Classification: Core / Non-Core — S. Objective_id D. Functional decomposition Unit_id: F01 — Business Sub-Function_id: F01-01 — Business sub-function name — Sub-Fun Description E. Business services Srv_id: SVC01 — Service Name — Service description — Function-ID F. Business processes Proc-id: P01 — Proc-name — Proc description — Proc class — Proc I/P — Supplier of i/p — Process o/p G. Business function to business process matrix Unit id: U01 — Business function(s) id: F01 — Contract: Realizes/owns — Process id: P01
7	Template (III)	A1. Baseline applications Application id: App 01 — Application name — Application version — Application description — Vendor B1. Application portfolio summary Application id: App 01 — Unit id — Function id: F01 — App name — App des — Bus owner — App status C1. Application portfolio details Function id: F01 — Process id — App id — Functional component — Primary user — App type

REFERENCES

[1] K. Hinkelmann, A. Gerber, D. Karagiannis, B. Thoenssen, A. Van Der Merwe, and R. Woitsch, "A new paradigm for the continuous alignment of business and IT: Combining enterprise architecture modelling and enterprise ontology," *Computers in Industry*, vol. 79, pp. 77–86, Jun. 2016, doi: 10.1016/j.compind.2015.07.009.

[2] ISO, "ISO/IEC/IEEE 42010:2011," *International Organization for Standardization*. 2011, Accessed: Jul. 05, 2021. [Online]. Available: https://www.iso.org/standard/50508.html.

[3] M. Alaeddini and S. Salekfard, "Investigating the role of an enterprise architecture project in the business-IT alignment in Iran," *Information Systems Frontiers*, vol. 15, no. 1, pp. 67–88, Oct. 2013, doi: 10.1007/s10796-011-9332-y.

[4] A. M. Clark, B. L. Atkin, M. P. Betts, and D. A. Smith, "Benchmarking the use of IT to support supplier management in construction," *Electronic Journal of Information Technology in Construction*, vol. 4, pp. 1–16, 1999.

[5] Department of Defense, "DODAF - DOD Architecture Framework Version 2.02 - DOD Deputy Chief Information Officer." 2015, Accessed: Jul. 05, 2021. [Online]. Available: https://dodcio.defense.gov/Library/DoD-Architecture-Framework/dodaf20_background/%0Ahttp://dodcio.defense.gov/Library/DoDArchitectureFramework.aspx.

[6] "Federal Enterprise Architecture Framework," *the White House President Barack Obama*, 2021. https://obamawhitehouse.archives.gov/sites/default/files/omb/assets/egov_docs/fea_v2.pdf (accessed Jul. 05, 2021).

[7] J. A. Zachman, "A framework for information systems architecture," *IBM Systems Journal*, vol. 26, no. 3, pp. 276–292, 2010, doi: 10.1147/sj.263.0276.

[8] J. L. G. Dietz *et al.*, "The discipline of enterprise engineering," *International Journal of Organisational Design and Engineering*, vol. 3, no. 1, p. 86, 2013, doi: 10.1504/IJODE.2013.053669.

[9] E. J.Adwan and A. Al-Soufi, "A Review of ICT Technology In Construction," *International Journal of Managing Information Technology*, vol. 8, no. 3/4, pp. 01–21, Nov. 2016, doi: 10.5121/ijmit.2016.8401.

[10] E. J.adwan and A. Al-Soufi, "A review of ict applications in construction," *International Journal on Informatics Visualization*, vol. 2, no. 4, pp. 279–285, Aug. 2018, doi: 10.30630/joiv.2.4.163.

[11] R. Cloutier, G. Muller, D. Verma, R. Nilchiani, E. Hole, and M. Bone, "The Concept of Reference Architectures," *Systems Engineering*, p. n/a--n/a, 2009, doi: 10.1002/sys.20129.

[12] K. D. Niemann, "Enterprise Architecture Management and its Role in IT Governance and IT Investment Planning," in *Information Resources Management*, {IGI} Global, 2011, pp. 996–1026.

[13] T. O. Group, "The TOGAF® Standard, 10th Edition," *The Open Group*, 2021. https://www.opengroup.org/togaf (accessed Jul. 05, 2021).

[14] S. H. Spewak, *Enterprise Architecture Planning*, vol. 2, no. 8. John Wiley & Sons: John Wiley & Sons, 1997.

[15] M. R. Dube and S. K. Dixit, "Comprehensive measurement framework for enterprise architectures," *Designing Enterprise Architecture Frameworks: Integrating Business Processes with IT Infrastructure*, vol. 3, no. 4, pp. 1–32, Aug. 2016, doi: 10.5121/ijcsit.2011.3406.

[16] R. O. Thomas, "Understanding the term reference model in information systems research: History, literature analysis and explanation," in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 3812 LNCS, Springer Berlin Heidelberg, 2005, pp. 484–496.

[17] A. R. A. Ahmadi, F. Soltani, and M. Gheitasi, "An ICT technical reference model for Iran Universities," in *Proceedings - International Conference on Information Technology-New Generations, ITNG 2007*, Apr. 2007, pp. 537–542, doi: 10.1109/ITNG.2007.33.

[18] M. Gammelgård, Å. Lindström, and M. Simonsson, "A reference model for IT management responsibilities," Oct. 2006, doi: 10.1109/EDOCW.2006.13.
[19] M. Pesic and W. M. van der Aalst, "Towards a reference model for work distribution in workflow management systems," in *Business Process Reference Models*, 2005, p. 30, [Online]. Available: http://www.researchgate.net/profile/Jan_Recker/publication/27464929_On_the_syntax_of_reference_model_configuration_Transforming_the_C-EPC_into_lawful_EPC_models/links/00b4952a9216f58327000000.pdf#page=37.
[20] O. Novotný, "KIT IS/ICT Management Reference Model," 2007, [Online]. Available: http://www.cssi.cz/cssi/system/files/all/novotny.pdf.
[21] A. R. Hevner, S. T. March, J. Park, and S. Ram, "Design science in information systems research," *MIS Quarterly: Management Information Systems*, vol. 28, no. 1, pp. 75–105, 2004, doi: 10.2307/25148625.
[22] K. Peffers, T. Tuunanen, M. A. Rothenberger, and S. Chatterjee, "A design science research methodology for information systems research," *Journal of Management Information Systems*, vol. 24, no. 3, pp. 45–77, Dec. 2007, doi: 10.2753/MIS0742-1222240302.
[23] R. K.Yin, "Case study research and applications: Design and methods," *Journal of Hospitality & Tourism Research*, vol. 53, no. 5. pp. 277–278, Jun. 2018, [Online]. Available: https://us.sagepub.com/en-us/nam/case-study-research-and-applications/book250150.
[24] M. Shakir, "The selection of case studies: Strategies and their applications to IS implementation cases studies. Maha Shakir," *Research Letters in the Information and Mathematical Sciences*, vol. 3, no. 3, pp. 191–198, 2002, [Online]. Available: http://hdl.handle.net/10179/4373.
[25] A. Bryman, *Social Research Methods*, Fifth Edit. London: Oxford University Press, 2016.
[26] J. W. Creswell, *Qualitative Inquiry & Research Design: choosing among five approaches*, vol. 2. 2007.
[27] J. Ritchie, J. Lewis, C. M. Nicholls, and R. Ormston, "Qualitative research practice: a guide for social science students and researchers," *Choice Reviews Online*, vol. 41, no. 03, pp. 41-1319-41–1319, Nov. 2003, doi: 10.5860/CHOICE.41-1319.
[28] A. Habibi, A. Sarafrazi, and S. Izadyar, "Delphi technique theoretical framework in qualitative research," *The International Journal Of Engineering And Science (IJES)*, vol. 3, no. 4, pp. 8–13, 2014.
[29] J. Iden, B. Tessem, and T. Päivärinta, "Problems in the interplay of development and IT operations in system development projects: A Delphi study of Norwegian IT experts," *Information and Software Technology*, vol. 53, no. 4, pp. 394–406, Apr. 2011, doi: 10.1016/j.infsof.2010.12.002.
[30] N. Elangovan and R. Rajendran, "Conceptual model: A framework for institutionalizing the vigor in business research," *Indian Business Management*, no. 4, pp. 1–32, 2015, [Online]. Available: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3515944Jun2.

BIOGRAPHIES OF AUTHORS

Ehab Juma Adwan is an Assistant professor of Information Systems at the University of Bahrain. He earned a Ph.D. in Computer Science & Engineering,2016 from the University of Bahrain (UOB), with advanced PG degree from George Mason University, USA. He earned a PG.D. in computing,2008, from the University of York, UK. He earned an M.Sc. in Computer Science, 2004, University of Bahrain (UOB), and earned his B.Sc. in Electronics & Computer Science in 1996 from The American University in Cairo (AUC). His research is focused on Enterprise Architecture, IS Architecture, SW Architecture, Systems Eng, and Systems Analysis & Design. Currently, most of his postgraduate supervision emphasis is on ICT in Smart City, Cloud computing, ICT in Construction, and Mobile app development. He can be contacted at email: eadwan@uob.edu.bh.

Ali Al-Soufi is an x-Associate professor of Information Systems at University of Bahrain. He has earned his PhD in computer science in 1994 from Nottingham University, UK. Worked for Bahrain Telecom Co for 8 years as a Senior Manager Application Programme, where he overlooked number of mega IS Application projects. Worked at Arab Open University as Director of IT program & Assistant Director for Business Development during 2007-2010. He is a PT consultant in Bahrain Information and e-Government Authority (iGA) in the area of Enterprise Architecture and Strategic Planning. He is an active member of the Bahrain National ICT Governance Committee. His specializations are Strategic IT Planning and Governance, IT project management, Enterprise Architecture and Information Systems in Organization. He can be contacted at email: ali.alsoufi@gmail.com.