BIRMINGHAM CITY
University

ARCOM Doctoral Workshop on

Construction Education in the New Digital Age

Wednesday 4th November 2015

School of Engineering and the Built Environment
Birmingham City University,
Birmingham B4 7XG, United Kingdom

Workshop Chairs:
Professor David Boyd
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ASSOCIATION OF RESEARCHERS IN CONSTRUCTION MANAGEMENT

CIB W089 - Building Research and Education

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Construction Education in the New Digital Age

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ARCOM Doctoral Workshop

Construction Education in the New Digital Age

Programme

Birmingham City University, Birmingham UK

Wednesday 4th November 2015

Time	Paper	Author
10.30-10.55	Arrivals and Registration	
10.55 – 11.00	Welcome and Introduction	Professor David Boyd Birmingham City University Dr Ani Raiden Nottingham Trent University
11.00 – 11.30	Keynote Address: Exploring the Potential of Digitally Enhanced Education	Professor Nick Morton Birmingham City University
11.30 – 12.00	BIM Media Implications on Architectural Design Thinking	Danilo Gomes University of Huddersfield
12.00 - 12.30	Turning Knowledge into Action: skills development and challenges in BIM projects	Siva Ganeshamoorthy Birmingham City University
12.30 – 13.00	Incorporating Building Information Modelling within the Construction Curriculum in the UK	Anas Bataw The University of Manchester
13.00 – 13.30	Buffet Lunch	
13.30 – 14.00	Construction Educations Requirements for Achieving Level 2 and 3 BIM	Adedotun Ojo University of Central Lancashire
14.30 – 15.00	Construction Learning and Education: exploring synergies through holistic reflection	Gloria Unoma Ene University of Central Lancashire
15.00 – 15.15	Break (refreshments)	
15.15 – 16.00	Discussion	Professor David Boyd Dr Niraj Thurairajah Birmingham City University
16.15	End	

Introduction

Construction education is at a watershed! While construction education provides knowledge and skills from the past, we are acutely aware that dramatic change is rushing towards us as a result of the rise of the information world and the computer and communications technology that supports it. Even though these inadequacies have raised major concerns, we are unsure what to do as the future is not obvious.

We know that our education and teaching must prepare students for this new, but uncertain, future. However, we need to educate ourselves first in understanding the world of information and its uncertainties. This workshop is arranged to provide that for our academics and educators. We are researching our future.

The BIM tool, which forms the focus of many of the papers here, is the start of these changes. As the papers reveal, we know about the form and operation but little about its implementation. As a result we will not have ready-made solutions but need to be proactive in developing these solutions and the skills to support them. Apart from BIM, e-commerce, integrated logistics, offsite manufacture and manufacture to order are some of the other novel ideas that would change construction processes in the near future. To crown these changes, we must also acknowledge that IT developments will significantly impact on education itself.

We need more research to cope with this. We need more discussions and workshops to find a collective purpose to address our future.

ARCOM also seeks to encourage and advance early career researchers. It does this through such workshops in order to develop the research community not just academically but socially so that it is sustainable for the future. This workshop is uniquely supported by CHOBE, the Council of Heads of the Built Environment and CIB W089 Building research and Education both of whom are at the forefront of developing a response to the educational changes. It is these integrated working practices which will be required for future construction education.

Professor David Boyd
Dr Niraj Thurairajah

Workshop Convenors
Birmingham City University

INCORPORATING BUILDING INFORMATION MODELLING WITHIN THE CONSTRUCTION CURRICULUM IN THE UNITED KINGDOM (UK)

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There has been a significant progress in the use of Building Information Modelling (BIM) around the world, especially in the last decade. In several countries, BIM has been employed into practice. However, the United Kingdom (UK) has not yet made noticeable use of BIM, although there are strong government policies in place to ensure the adoption of Level 2 BIM by 2016 on all UK public projects. Since the UK government is leading the implementation of BIM strategies, the higher education sector has become interested in developing new ways in teaching BIM process. Though, educational institutions in the UK are facing many difficulties, partly due to the novelty of the technology and the dilemma of current methods of teaching. Although, some educational institutions within the UK have begun examining the importance of preparing their students for a career in a BIM-enabled work environment. Yet, educators in universities are facing the same problems as many professionals within industry such as the misconceptions of the reality of BIM and the lack of understanding on how to implement the concepts of BIM. Preliminary research findings derived from an investigation of the current teaching methods is outlined to better understand and evaluate the contribution of BIM to the educational experience of students in construction degrees. Fundamentally focusing on balancing the students' requirements and the industry's desires to propose "best practice for teaching BIM within the UK", in order to assist educational institutions on developing their teaching approaches to suit the evolution of BIM while maintaining the underlying principles of teaching construction degrees.

Keywords: BIM Education and training, BIM in curriculum, BIM in Construction courses, BIM in UK Education, BIM in Academia.

INTRODUCTION

Building Information Modeling (BIM) is seen as a fundamental change to the industry and all professionals serving it. The policy of implementing BIM within the UK by 2016 has indicating that the government is aware and interested in BIM benefits to enhance the control of time, cost and quality that BIM is proposed to offer to everyone involved including clients, designers, contractors, suppliers and facilities managers. Subsequently, many stakeholders have shown a slow but definite approach towards using BIM. However, according to Young, et al. (2008) and Bataw, et al. (2014), the lack of BIM knowledge and skills in the UK created great constraints delaying the use of BIM and generated great concerns for many professionals working within the industry and students undertaking construction degrees at university levels

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BIM IN EDUCATION

A number of researchers have examined whether BIM concepts and tools should be taught to students at university levels. Dean (2007) concluded in overall that educational institutions should teach BIM to their students, stating that graduates with BIM skills have an advantage over graduates who lack BIM knowledge.

Correspondingly, some of the UK's largest graduates employers are concerned that their newly hired graduates will lack BIM knowledge, advanced computer skills and most importantly will lack the communication and team working skills that many graduates miss out as a result of studying construction degrees via the traditional methods (Dean, 2007). According to Fox and Hietanen (2007) students and graduates with BIM knowledge and skills are important individuals that can contribute to the use of BIM within their organisations.

In regards to construction students in the UK, recent study by Wesley (2013) indicated that only one Russell group University stated that BIM activities were introduced within their programmes with very little implications suggesting that undergraduate students were studying or even being made aware of BIM. This suggesting that many construction students would not be capable of working on projects using BIM once they graduate, which is generating a significant gap of knowledge that graduates and recruiting companies will face in the upcoming future.

Education at undergraduate levels in the UK will always be lagging behind the research being done at postgraduate level. In the case of BIM, it has been a subject researched for a number of years at postgraduate level. However, it was never introduced to the curriculum of the majority of educational establishments across the UK. This was due to the complexity of BIM theory and also the difficulty of the educational sector to introduce new technologies.

Approaches of teaching BIM

Through a literature review it was possible to identify how 125 schools are currently incorporating BIM into their curriculum; 97 schools are based in the United States and 28 in other countries (none in the UK). These schools taught BIM differently, 70% of these schools have taught BIM within existing courses either by integrating BIM within existing modules or as an individual module, while 30% have generated a new course to teach BIM. The emerged three approaches were as following:

1. BIM integrated into existing modules

In simple terms, BIM tools, techniques and concepts were included within existing modules; this is usually done by developing the existing curriculum of each module to suit BIM practices. This structure appears to be the most preferred method used by the schools. However, it is the most complex approach and requires renovation of the existing modules.

2. BIM as an Individual Module

BIM tools, techniques and practices were also integrated within the course as a new single module usually named BIM, but not isolated from the evolved course discipline.

3. BIM as an Individual course

Some universities found it more functional to develop a course that contains all BIM tools, techniques, theories and practices. This teaching method was rarely used but seem to be very popular to students especially in postgraduate levels.

The used term “Module” is referred to each set of standardised parts or independent units that can be taught within a course. While the term “Course” is referred to the whole program of study.

These approaches were designed in the initial steps of adopting BIM and were used by many construction courses around the world. However, universities in the UK are still uncertain which approach is most appropriate to adopt and therefore are behind with teaching BIM to construction students in all university levels. Hence, this research will focus on determining the most suitable approach to incorporate BIM within construction courses in the UK from the student’s perspectives and preferences.

As the case with any corporation, the customers must be considered and consulted when developing new services. In the case of the university courses, the customers are both industrial employers and students. As explained above, the industrial employers are concerned with BIM and are already seeking to employ graduates with BIM knowledge. Therefore, a survey was required to better understand the student’s requirements to raise their aspirations and educate them to become more discerning and competitive in the construction industry. Therefore, asking the students to take part in identifying the most suitable form of education is essential.

QUESTIONNAIRE SURVEY

An online survey was developed to outline the requirements and understanding of current construction students on teaching BIM within construction courses in the UK, sent to students undertaking construction courses in the UK from all university levels in the academic year 2013-2014. The survey collected data from students regarding their views on BIM and best practices of teaching BIM. The survey also inquired about the students’ expectations of BIM knowledge upon graduation and who they believe is reliable to provide and teach this knowledge.

An online link to the survey was emailed on three occasions to the sampled students within three-months period, between the months of January and April 2014. Responses were received from 1856 construction students from different programmes and academic levels, generating a response rate from 26 Universities in the UK teaching construction courses.

Sampling approach

The probability sampling technique was used to select the samples of construction courses to carry out this questionnaire survey. However, the student’s population in the sampled construction courses was too large and was almost impossible and time consuming to identify every student of the population to choose a specific sample for this questionnaire survey. Therefore, the non-probability sampling technique was the most appropriate to generate the best possible samples of students from the sampled courses.

The simple random sampling technique was used to increases sample's representativeness of the population to generate statistical inferences and allow for generalisation, where every construction course had greater chance and equal opportunity for selection. While sampling errors and sampling bias were minimised

However, the snowball sampling technique was used in the later stage due to the difficulty of accessing information on each and every student in the sampled courses. Where the snowball sampling technique was much easier, quicker and cheaper than probability sampling techniques to produce sufficient data.

The process started by breaking down the list of each construction course to the academic years. Then each academic year was assembled separately where similar academic years were gathered in one table, this process was carried out with every academic year. Once all the academic years were assembled and the population was distinct, the researcher used the simple random sampling technique to randomly select 25 of each year i.e. (25 x 1st year programmes, 25 x 2nd year programmes, 25 x and 3rd year programmes) adding up to construction courses from 29 different Universities in the UK. The simple random sampling technique was used for this stage to guarantee equal chance (probability) for each university and each academic year to be selected for inclusion in the sample.

Once the samples of the universities and academic years were selected, it was easier to identify and contact academics teaching members in these universities rather then the students, hence the Snowballing sampling technique was adapted as it is the most suitable and usable technique for sampling such a large amount of students, where the teaching academics were initially contacted to identify further suitable members (Students). According to Hussey (1997) and Saunders et al., (2003) snowball sampling technique can identify the only possibility when populations are difficult to identify.

RESULTS AND SUMMARY

The students were asked, “Has/ will BIM be taught in your current course?” with one option to choose from “Yes”, “No”, “Not sure” and “if yes (please describe)”. 27% (N= 501) responded “Yes”, 54% (N= 1002) responded “No”, while 19% (N= 353) responded with “Not sure”.

The 54% (N= 1002) who responded with “ No” were students from 18 different universities, indicating that at least 18 construction courses in the UK do not teach BIM to their students at university levels. However, students undertaking these construction courses will soon be graduates seeking for work within the industry but without any BIM knowledge, BIM qualifications or BIM experience.

The 27% who responded with “ Yes” were students from 6 different construction courses, at the beginning it seemed like a good number of universities are teaching BIM. However, when theses students were asked “If yes, please explain”, most of descriptions indicated that students were referring to CAD rather than BIM.

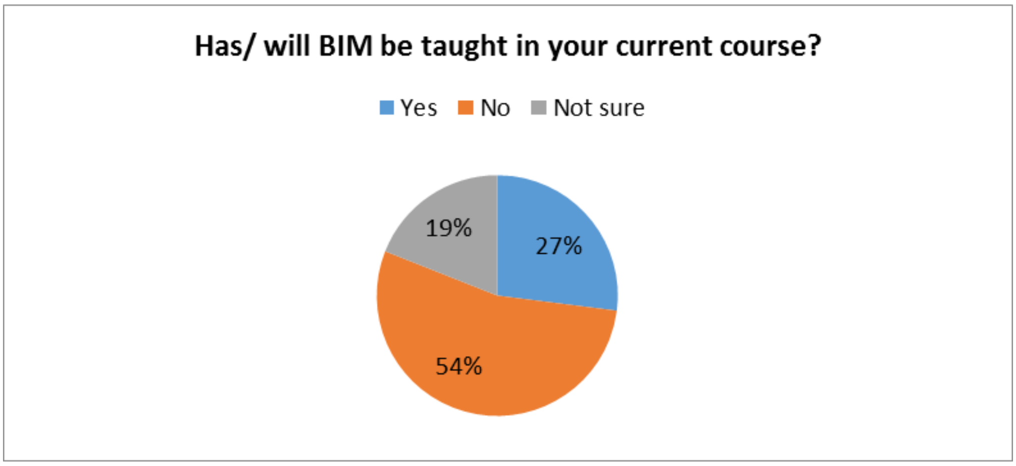

Figure 1. Has/ will BIM be taught in your current course? (N = 1856)

Also students were asked "which way do you prefer to learn BIM?" the respondents were asked to select "all that apply" when answering this question. 69% (N= 1281) Prefer to learn BIM integrated within their existing courses, 13% (N= 241) prefer to learn BIM (ONLY) within multidiscipline modules, combining different disciplines together, while 29% (N= 538) prefer the combination of the above i.e. learn BIM within the existing courses and within multidiscipline modules (combining different disciplines together). However, 9% (N= 167) prefer a dedicated BIM degree and 7% (N= 130) prefer to learn BIM in an Independent BIM training courses.

These results indicated that 1281 current construction students prefer to learn BIM integrated within their existing courses, which means that this method is the most preferred by the construction students in the UK. Furthermore, out of the 1281 students 538 also prefer to learn BIM within multidiscipline modules, combining different disciplines together.

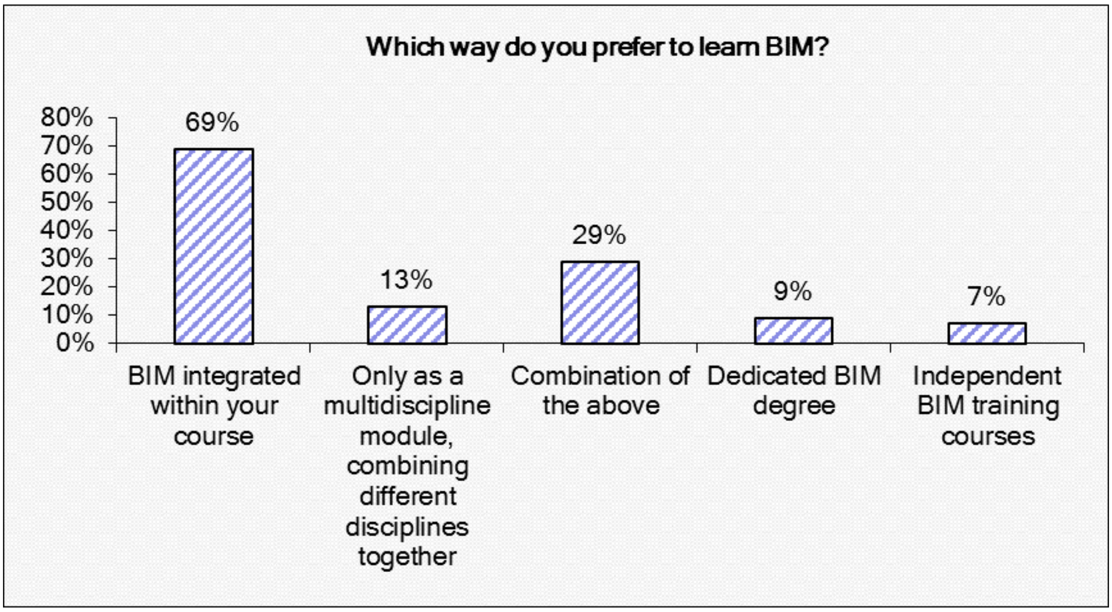

Figure 2. Which way do you prefer to learn BIM? (N = 1856)

In the last but not least question of the survey, the students were asked "Who should have the most responsibility in preparing Students/ Graduates to work with BIM?". 80% (N= 1485) of the students suggested that universities should be responsible for preparing students with BIM knowledge, while 17% (N= 316) of the students suggested that the employers should prepare the students/ graduates toward working with BIM and only 3% (N= 56) of the students suggested that the software companies should be responsible in preparing students/ graduates to work with BIM.

This demonstrates that the majority of construction students mostly rely on their universities to prepare them for the industry. Indicating that Universities are required to rearrange some of the current programmes to better equip students for the growing demand of BIM. Therefore, universities should prepare their construction courses with the support of the major employers and software companies, to provide a theoretical understanding to their students with practical experiences and approaches in unison with the Software Companies to give practical examples of how it is intended to work.

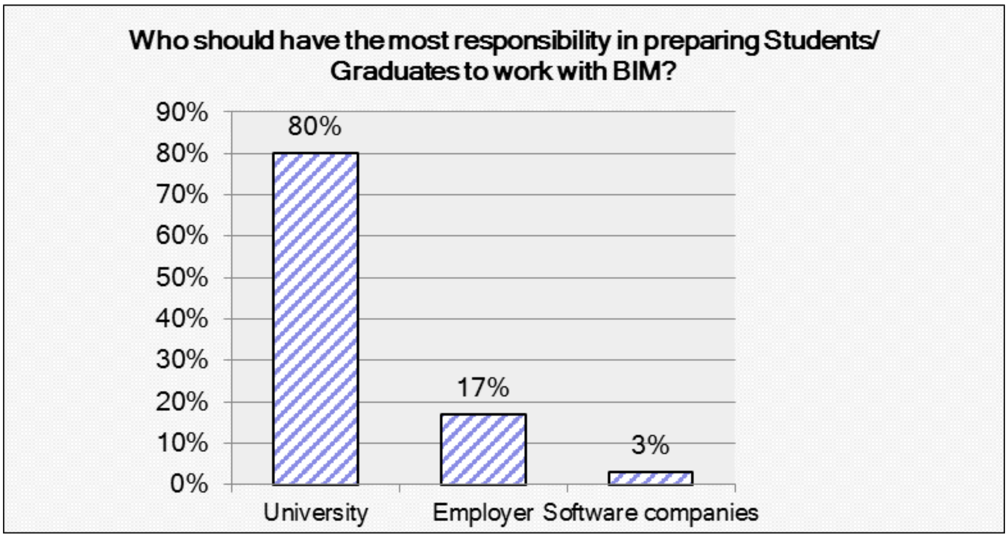

Figure 3. Responsibility in preparing students/ graduates to work with BIM? (N=1856)

DISCUSSION

It is essential to comment on the response rates for this questionnaire survey. Responses were received from 1856 construction students in 26 different universities. This was encouraging for the authors and will also be encouraging to academics and professionals supporting the involvement of BIM within construction courses. The survey results concluded the following:

- The positive response rates indicate that students are taking an interest in learning BIM.
- In terms of teaching BIM, none of the results indicates real implementation of BIM within construction programmes in the UK.
- Construction students from 18 different universities in the UK have indicated that BIM was not even introduced within their courses, which means that these students will soon be graduates seeking work within the industry but without any BIM knowledge, BIM qualifications or BIM experience.

- Even though it wasn't specifically inquired in the questionnaire, the majority of the respondents stated that they are currently undertaking Autodesk Revit within their courses, which indicates that universities are capable of teaching such technologies and the students are capable of learning these technologies.
- Construction students in their final year have indicated that BIM research topics have been introduced as one of the options for the dissertation themes to undertake in their final year as part of completing their construction course.
- None of the respondents stated or implied that they did not feel that BIM was important for their learning curve.
- As the interest of implementing BIM is growing, construction courses across the UK must be rearranged to better equip the students for the growing demand of BIM knowledge within the construction sector.

CONCLUSIONS AND RECOMMENDATION

The majority of the responding students indicated that the preferred method of learning BIM is by fully integrating BIM within the current construction courses. While more than the third also prefer to learn BIM within multidiscipline modules by combining different disciplines together.

The integration of BIM principles within the construction courses in the UK indicates that the core standards of the current taught construction courses will not change. Rather, BIM standards and capabilities can be introduced within the current curriculum to assist the students with understanding construction disciplines and concepts and to enhance the students' practical abilities and problem solving.

In Recommendation, educators should not commit to narrowing down the existing construction courses to a certain topic such as BIM even if it is currently dominating the industry. BIM is an idea that might fade in the near or distant future but the construction disciplines are professions that have existed for generations and will continue to do so, embracing the same knowledge and practices. However, it requires improvements to fit with the 21st century. The essential aspect of teaching BIM is technology and working in a collaborative environment, and that is what the educators should concentrate on. Whether BIM ideology and tools can be taught within the construction courses in the UK, construction will always be taught.

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TURNING KNOWLEDGE INTO ACTION: SKILLS DEVELOPMENT AND CHALLENGES IN BIM PROJECTS

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Building Information Modelling (BIM) is a recent technology introduced in construction industry to increase productivity in construction projects. However, construction industry is slow in adopting new technologies due to skills challenges within project teams. Therefore the main objective of this paper is to explore the required skills to complete BIM related activities and to identify the approach taken in the industry to acquire these skills. Semi structured interviews were conducted with professionals working in BIM enabled construction projects to understand current skills challenges faced by project teams and to attain knowledge about the skills required to effectively complete BIM construction projects. Analysis of the results includes the identification of current skills challenges and the key issues in adopting skills for the improvement of project performance and productivity. The paper presents evidence that skills during a technology change such as BIM can be gained through four main stages such as core knowledge development, understanding practice, using knowledge in practice and continuous practice. However the evidence also suggests that turning knowledge into action is not a linear process especially in the early days of a technological change.

Keywords: Building Information Modelling (BIM), Construction Industry, Productivity, Skills, Technology.

INTRODUCTION

The Construction industry lags behind other industries in terms of efficiency and productivity due to its fragmented nature and its resistance to adopt new technologies introduced within the construction projects (Murphy, 2014). New technologies within the construction industry are introduced to alter and create quicker ways to deliver goods and services (Corney, 1997), high performance work practices (Bresnahan et al, 2002), skills development (Hansushek and Woessmann, 2008) and high level of productivity (UKCES, 2015). In addition it has also improved the specialised and operative activities involved within the construction industry (Bosworth, 2013). Moreover recent studies in construction industry highlight the skills challenges as a major barrier in achieving high level of productivity (Blooms et al, 2004; Grant et al, 2013; UKCES, 2015). Focusing on resolving skills related issues provide an opportunity to improve and avoid these difficulties faced in construction industry. According to the construction skills report (2004) employers’ skills requirements need to be taken into consideration to introduce complete change and to enhance the efficiency of the construction projects. Building Information Modelling (BIM) which

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is one of the recent technologies is introduced within the construction industry to improve construction projects. However, BIM is not utilised to its potential due to skills related challenges faced in the construction industry. The research discussed in this paper studies these skills issues and identifies a way forward for the UK construction industry.

LITERATURE REVIEW

BIM in construction industry

Construction industry has been continuously changing with the introduction of new technologies. Moreover, the introduction of new technologies have led the production process to take a ‘techno-economic view’ (Cardoso, 2000) which promotes the professionals to adopt higher and broader varieties of duties and skills (Lundval, 2004). According to Yisa et al (1996) this change cannot be avoided either by an individuals or organisation involved in construction industry. Among the technology used within the construction industry Building Information Modelling (BIM) is a recent technological development seeking to integrate processes throughout the entire project lifecycle (Aouad and Arayici, 2010). The importance of BIM adaptation is highlighted in several studies (Suermann and Issa, 2009; Azhar, 2011; Cabinet Office, 2011). Furthermore, recent BIM projects in the UK have established the immediate benefits such as clash detection, cost reduction, clear scheduling and swifter fabrication using data from BIM models (Nisbet and Dinesen, 2010). BIM can be defined as "digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition" (CPIC, 2011). However, Davidson et al (2009) describes BIM as ‘a disruptive technology’ as it will transform many aspects of the construction industry. On the other hand National BIM report (2012) has mentioned BIM as "a collaborative process of design, procurement and building operations". Furthermore, Kymmell (2008) claimed BIM as ‘‘an intelligence that mitigates from 2D to 3D and creating intelligent and multi-dimensional building models’’. There are many ways of looking at BIM; however, this study has viewed BIM as a way of working which is a combination of building information modelling and information management in a team environment, where all team members work to the same standards. In BIM, skills related issues are more centred on technology and people therefore this particular view is adopted for this study.

UK government has mandated to use BIM in public sector projects since 2016 (Cabinet Office, 2011) therefore construction companies have slowly started to adopt BIM in their construction projects. However, not having the necessary skills to use BIM within the construction project teams has been identified as a major barrier in the effective use of BIM (Cheng, 2006; Esposto, 2008; Hartmann & Fischer, 2008; Gu & London, 2010; Wong et al, 2011). Eadie et al (2013) from their study established that even though there are other reasons for not using BIM, lack of expertise within the project team is the most common reason for not using BIM within the construction projects. Moreover BCIS (2011), CIOB (2013) and NBS (2014) reports indicate the urgent needs for appropriate skills in BIM construction projects. In similar the study by Giles et al (2004) argue that existing workforce skills needs to be changed to meet client's expectations during a technological change.

The term skills can be defined in different ways. Becker (1964) and HM Treasury (2006) define skills as the capabilities of doing a certain occupation or range of activities. Odusami (2002) states skills are abilities to perform the task better than the average including the ability to translate the knowledge into action. Moreover, skills are also looked from other point of views such as expertise (Wood, 1988), emotional reaction (Boyatzis et al, 2002) and dexterity and knowledge of the workforce (Mangham and Silver, 1986). In general, skills development encourages economic performance (OECD, 2000; O'mahoney and de Boer, 2002), innovation and flexibility (Leiponen, 2005). Moreover it helps to determine individual's employability to productivity (Leuven, 2005; Leitch review, 2006) and business profitability (Bosworth, 2013). The study conducted by Autor et al (1998) discussed about upgrading skills during the implementation of IT from 1970s to 1990s and identified that the use of computers have increased throughout the years. Alshawi and Faraj (2002) discussed about the development of technology and effective implementation. Initially this study investigated about sharing project information with the IFC (Industry Foundation Class) and highlighted the difficulties faced in achieving successful implementation in construction industry. Hwang (2003) studied about the diffusion of information and changes in skills in the UK during 1980s and investigated how they have changed in later years. On the other hand some studies have identified technical skills, management skills, interpersonal skills, managerial skills and administrative skills as the primary skills to work with BIM (Kymmell, 2008;Gu and London,2010;Succar,2013). Moreover, recent studies have focused skills issues in relation to economic performance (CITB, 2015; UKCES, 2015).

Skills Challenges and Economic performance

The UK economy has been growing since 2013 and has increased 2.8% in 2014 (ONS, 2014). This has improved job opportunities and employment rate however the productivity is stagnant and has fallen further down since 2007 (ONS, 2015). Productivity is essential to be considered because it determines the competitiveness for the business and wages for people at work (UKCES, 2015). According to HM Treasury (1988) productivity is 'a fundamental yardstick of economic performance' and the UK government is not productive enough compared to the other countries due to not performing to the standards. The construction industry has been one of the main engines of UK economic growth during 2014 (CITB, 2015) nevertheless still UK's productivity gap is driven back due to skills challenges faced in the construction industry. The UK firms have reported that they are reluctant to invest in new technologies because of the issues in maintaining and upgrading skills that are required to complete a job.

People with skills in jobs play an important and sustainable part in the UK productivity growth. However skills related challenges are one of the major barriers for lower level of the productivity and they hold employees back from achieving targets (CITB, 2013). Therefore, currently there is a need for people who are capable, agile and able to respond to the challenges presented by the new technologies. This is also highlighted in Sami's (2008) study where he mentioned more attention is needed to reskill, multi-skill or upskill professionals in the construction industry to successfully achieve project targets. In this study skill challenges have been viewed from skills gaps, skills shortages and latent skills shortages point of views in order to improve productivity. Skills gaps occur within the workplace where a firm has employees but they are not skilled enough to meet the organisation's objectives (Campbell et al., 2001). Whereas skills shortages happen when there is shortage of suitable skilled people in labour market to fill in the vacancies (Barnes and Hogarth, 2001). Campbell et al (2001) state that skills gap affect more employers compare to skills shortages. One of the reasons for skills gaps is employers feel they are not recruiting people with the right skills. In UK, skills gaps include the basic skills (literacy, numeracy and computer skills), intermediate skills, and leadership and management skills. In addition there is also evidence of generic skills gaps such as motivation and attitude to learn (Bloom et al., 2004). Conversely Crafts and O'Mahoney (2001) believe that skills shortage plays a significant role towards the level of productivity. Supporting this Bloom et al (2004) mentioned that skills shortages are clear within UK construction industry and at the same time whatever the perception on scale of shortage, there is a growing demand for skills. Apart from this, latent skills shortage is also an issue, which is a situation where establishment fall short of what might be considered good or best practice which might be the reflection of low skills or poor business performance, even though there is no report of recruited problem or skills gap (Hogarth,2001). Generally this occurs when the organisation starts to manage a project with existing skills without being aware of necessary skills. Chan and Cooper (2006) claim that this situation is more frequent in construction industry because construction practitioners often do not know what skills they need to produce positive project outcomes.

Looking at skills challenges from an economics perspective, it can be argued that UK construction industry needs to identify the skills they require to successfully deliver product and services with the aid of new technology. Although the literature states that skills challenges is a major barrier to achieve higher productivity there is no clear evidence of how these required skills are achieved within the construction projects during an implementation of new technologies. Endogenous growth theory states that technological changes are usually skilled based and there is a need to have necessary skills among the employees to improve the productivity, and to respond to competitive environment. In this theory human capital is considered as one of the primary drivers of growth and the view taken in this paper consider that skills improvement is a key factor of human capital that counts for economic growth. This views is been supported by Bloom et al (2004) where he claims even though new technologies are out there significant amount of knowledge and skills is not there to work with those new technologies. Therefore this study focus on identifying the current skills challenges in UK construction industry during the implementation of new technology and the way they are achieved within the construction projects to improve productivity.

METHODOLOGY

Philosophical worldviews have influence on practice although they are often implicit within the research (Slife and Williams, 1995). Critical realism is a philosophical perspective about reality and human knowledge (Bhaskar, 2008). This view accepts the existence of an intransitive domain of objective knowledge but also accepts that it can never be purely unmediated since access to this domain is always socially constructed and is always subject to change. Consequently key to a robust enquiry is to adopt a wide critical perspective on both ideas and practices (Cidik et al, 2013).

This is appropriate for this study because the perspective of critical realism considers the BIM technology as existing independent of people who interact with it and having influence in development of knowledge and skills which are socially constructed.

The purpose of this investigation is to explore how project teams work with a new technology and to understand how they achieve the skills needed to complete the tasks in BIM environment. This research involves with detailed description of the situation, observed behaviour and interaction with people to ask about their experiences and beliefs. Therefore, qualitative research is adopted as a method best suited to explore the new area. Qualitative research is ‘‘Multi-method in focus, involving an interpretive, naturalistic approach to its subject matter’’ (Denzin and Lincoln, 1994). In other words it is a method of exploring and understanding the meaning where individuals or groups ascribe to a social or human problem (Creswell, 2008). The purpose of this qualitative method study is to understand how construction project team members gain their knowledge and skills during technology change within the construction industry. Data for the qualitative analysis was collected through semi structured interviews conducted with BIM experts working in the UK construction industry. There are many project participants involved in construction projects however this study has only focused on the BIM managers and BIM coordinators who closely work within BIM environment. BIM managers interviewed were managing and coordinating people who were involved in BIM processes. In addition they provide the appropriate guidance for the team members while decision making. At the same time BIM coordinators were involved in forming models and tools and to support the functions and to operate alongside with BIM technicians.

Semi structured Interviews

In this study, as the initial step professionals working with BIM across UK construction industry were interviewed to understand the significance of skills related issues in BIM construction projects and to understand how they achieve skills during the implementation of BIM in UK construction projects. The purpose of this interview is to collect interviewee opinion about the skills required to complete BIM related activities and its impact on the productivity. In addition this method is chosen to understand the in-depth experiences and to explore individual perception of professionals engaged with BIM construction projects. Most of the interviewees were chosen through university contacts and some were selected from LinkedIn professional groups where their experience with BIM technology were more than 5 years and had quick access to BIM related information compared to other project participants. Two pilot studies were conducted with the construction professionals working with BIM before conducting the interviews. This has helped to refine the questions with appropriate wordings and to confirm whether the questions seems sensible to the interviewees. In semi structured interviews conducted across the UK, open-ended questions were employed to get a wider view of the situation and interpretation was done along the way. The data collected through semi structured interviews explains how the skills are achieved through out their experience working with BIM.

DATA ANALYSIS AND DISCUSSION

The data collected from the semi structured interviews with BIM experts were divided in four different stages such as core knowledge development, understanding practice, using knowledge in practice and continuous practice. It is concluded that after the continuous practice stage, employees maintained a high level of productivity.

Core knowledge development

BIM in construction industry is fairly a new concept and the construction project team members consider this as a new way of working. Most expressed that initially they were reluctant to use BIM and the understanding fundamental aspects of BIM enabled them to consider the new technology. This involved in understanding what BIM is and some of the benefits associated with it. According to the interviewees they then started to use BIM in their construction projects due to clients' request and to utilise BIM benefits to achieve more profits. Many BIM advantages were highlighted during the interview such as putting the right process on place, generating models for facility management, watching the on-going maintenance, increasing the speed in creating schedules and drawings, enhancing the coordination, risk management, reducing reworks through managing the errors in early stage of the project. Majority of the interviewees acknowledged that BIM implementation in future UK construction projects is beneficial however they agreed current skill challenges need to be resolved to fully utilise BIM. The interviewees acknowledged that the fundamental knowledge about BIM was gained through various learning methods such as degree programs/ education, self-learning, basic software training, attending meeting, conference and workshops. During the discussion they also mentioned that knowledge about BIM was hard to achieve in the earlier days due to lack of case studies and on-going projects however it is agreed that now there are plenty of guidance, protocols and case studies that can be referred easily.

Understanding practice

This stage involved the professionals understanding the distinction between theoretical and practical knowledge related to BIM. After gaining the basic knowledge and information about BIM, professionals started to step into the next stage which is the general understanding about BIM in practice. In this stage professionals obtain the holistic knowledge about BIM which includes information on theoretical background of BIM, software used, people involved and the way BIM process is managed. During this stage professionals started to understand how BIM is being used by the project participants in construction projects. Interviewees mentioned that this is generally achieved through observing or communicating with BIM champions working in on-going BIM construction projects. At end of this stage it gave them an overall picture of how BIM is being practiced within the construction industry and they were also able to differentiate the knowledge in practice from theoretical knowledge they have learnt.

Using knowledge in practice

In this stage after understanding the overall picture participants started to use BIM in their practice. Interviewees stated that in this stage they had to face several skills gaps such as detailing elements in BIM applications and using software , lack of understanding about family creation and detailed understanding, lack of knowledge about in putting the data into the objects and extracting it, process and standard gaps and lack of engineering. Moreover it has been realised that these gaps occur within internal workforce where professionals recruited are not deemed as a fully proficient. On the other hand some interviewees indicated that even though they think they have enough skills to work with BIM the project outcomes were not achieved to the required standards. This is due to latent skills shortage where skills gaps are unrecognised because project organisations have simply coped operationally without the necessary skills. This latent skills shortage is evident in some stakeholders such as sub-contractors, manufacturers and suppliers who are struggling to achieve project outcomes due to lack of involvement with BIM technology. In BIM projects latent skills shortages are derived from lack of defined project process, lack of understanding of role and responsibilities and frequent change of software to work with BIM. In addition this happens more often in BIM construction projects due lack of communications between the project team members. In other words the problems faced by the project team members are rarely discussed among them and in most of the situation doesn't not get reported to the top management. BIM professionals indicated that skills challenges are a major barrier in achieving positive project outcomes. This clearly demonstrates that skills gaps and latent skills shortages are significant constraints to performance. Interviewees believed that investment in skills could produce a radical shift in employees' perception of working which can lead to a higher level of productivity.

Interviewees also mentioned that they had made several mistakes due to lack of systematic approach, not fitting data into scheduling tool, lack of use of BIM sheets with the BIM execution plan, shifting to different software due to constant change of software, putting too many details and manual annotations in the BIM model and not having right understanding about BIM information. They believed that this is due to not having required skills and suggested that enhancing the necessary skills will help them to avoid these mistakes in other projects. Moreover they have identified certain skills such as level of understanding the overall process, understanding client's needs, awareness of disciplines, collaboration and communication with stakeholders, technological skills, coordination skills, engineering, commercial and management skills as the primary skills necessary to work with BIM.

Interviewees mentioned some of the constraints faced during working with BIM construction project were understanding the technology, lack of communication, lack of understanding the roles and responsibilities they fit in, different viewpoints and standards, lack of top management understanding, bringing everyone to the same page and providing training to different age groups . However they believed that improving the required skills could be useful to detect the conflicts in the early stage, understand the tools and the way software works, increase hands on practice with tools and software packages and encourage communications among the project team members. All the professionals interviewed strongly believe both formal (academia) and informal (industrial training) educations are essential to work efficiently with BIM. In this situation education provides the theoretical knowledge of BIM whereas training helps to understand BIM practice.

Continuous practice

In this final stage professionals acknowledged these identified skills are centred on three key areas which are BIM learning, BIM training and BIM practice. Challenges of using BIM in practice can only be gained by engaging in practice. This triggers the need to gain more understanding or training in specific areas. Interviewees claimed that with continuous practice they become a skilled personal with ability to deal with BIM issues in any project setting. However they also expressed that every project is unique and comes with its own BIM related challenges. Therefore they suggested more training, engaging with other BIM projects, following BIM courses, getting constant feedbacks about software from the newsletters, understanding the standards and setting out the project goals in the beginning of the project can be done to achieve better project outcomes. This stage could be claimed as the space where knowledge turns into action and required skills are achieved.

CONCLUSION

Skills challenges are one of the major barriers in achieving efficient project outcomes. At present, construction projects are introducing new technologies such as BIM to increase productivity. However this study has identified that skills gaps and latent skills shortages are major constraints in achieving better project outcomes in BIM construction projects. Therefore it is important to focus on upgrading skills during a technological change. This paper has identified understanding the overall process, understanding client's needs, awareness of disciplines, collaboration and communication with stakeholders, technological skills, coordination skills, engineering, commercial and management skills as primary skills to work with BIM. Moreover the study has concluded that these identified skills can be achieved through four main stages which are core knowledge development, understanding practice, using knowledge in practice and continuous practice. However the evidence also suggests that turning knowledge into action is not a linear process. BIM experts interviewed in this study suggest the knowledge development through these stages can be enhanced through more training, engaging with other BIM projects, following BIM courses, getting constant feedbacks about software from the newsletters, understanding the standards and setting out the project goals in the beginning of the project and communicating with BIM champions.

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BIM IMPLICATIONS ON ARCHITECTURAL DESIGN THINKING

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The introduction of Building Information Modelling (BIM) technology in the Built Environment industry promotes considerable challenges to architectural design practice. Proposed as a new approach to produce and communicate data in product delivery process of construction, it changes significantly the design media affecting mainly architect's creative process. Since BIM design tools are functionally structured differently from traditional CAD tools, it is possible to argue that, consequently, they affect the cognitive process involved in design. It raises the question of how architectural design thinking needs to change to be aligned with the possibilities of this new technology. This paper discuss on the current limitations and incongruences of architectural design thinking with a new design media (i.e. BIM), as well as, it proposes how it could be changed. Based on literature review this paper discuss how this new design media is different from traditional design approach considering design tools and, fundamentally discuss the way designers think and engage design knowledge into design activity. In this sense, the introduction of parametric thinking as new pattern of productive thinking in design seems to be inherent to the adoption of the new media. Such discussion highlight the urgency to align these technological changes with the development of design skills. This study than suggests that a possible way to facilitate BIM adoption on architecture practice would be based on the development of a new approach to diagramming, as a thinking tool, to potentially connect architectural design knowledge with the nature of BIM applications based in smart data in a shareable multidisciplinary context.

Keywords: BIM Adoption, Design Media, Design Cognition, Parametric Thinking, Architecture Education.

INTRODUCTION

Today as Architecture and Engineering are been established as a more digitally networked practice, based on distributed activities within and across disciplines, the design process turn to involve embedding intelligence in the formation and actualisation of spaces (Kocaturk and Medjoub, 2011). In the same technological base, innovation in design is now better seen as an outcome of an iterative and dynamic coordination of a cross-disciplinary intelligence that is distributed across various digital tools, people and organisations in a social context (Kocaturk and Medjoub, 2011).

The Building Information Modelling (BIM) approach introduces a change from a non-intelligent data to a BIM-based intelligent information system (Codinhoto et al. 2013), in which the system is based on a platform for shared visualisation. Basically, BIM tools provide means for visual management, creating a common ground for different stakeholders in design and construction process (Koskela, 2015).

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In this context, architecture expertise is being re-aligned (Kocaturk et al. 2012), and these changes are affecting architects' practice faster than other disciplines, and the main reason is that today architects are usually responsible to create basic models before the involvement of the other stakeholders in the BIM (Kiviniemi and Fischer, 2009).

The adoption of the BIM technology tries to mediate the challenge of gather all the language and tacit mental models of expert consultants that usually are involved on an average capital project delivery (CPD) (Akin, 2014). The same author argue that the most challenging aspect of adopting BIM is how to establish a correlation between digital models of building information with cognitive models of designers.

Although BIM systems provide more support for data transfer and integration, they are still not completely compatible with creative process happening during the conceptual design stages (Kocaturk and Medjdoub, 2011). As well as, some of the current parametric functions cannot translate specific design aspects due to computational limitations of generative software packages (Kocaturk and Medjdoub, 2011). Maybe one of the biggest challenges for BIM adoption is regarded on how to address its distributed nature of gather knowledge as formatted information across individuals, social groups, and media, in Architectural education (Kocaturk et al., 2012), which has historically been conducted as a development process of an individual type of thinking.

Considering that, this paper first present a discussion to describe the motivation and the rationale for such change in architecture design context, pointing out the essentials of BIM as new media for design and how it definitively affects architectural design practice. Based on a literature review, this study presents a proposition on how should be managed this transitional process embracing three main topics: the structure of new BIM applications, the nature of design knowledge and a new approach to design thinking in architecture.

THE NEED TO CHANGE TO A NEW DESIGN MEDIA

For centuries, architectural design has relied upon a particular kind of media: drawings (Kiviniemi and Fischer, 2009). According to the same authors, the establishment of drawings as the main media for design represented a formalized visual language, which consequently improved communication among stakeholders. Majorly consisting of a standardized 2D abstraction of a building, this media enabled the production of more detailed documentation of building instructions.

When we consider BIM, the media becomes a computerised process in which the key physical and functional characteristics of a building project are designed (conceived and modelled/represented) in a 'virtual' model (Barnes and Davies, 2014). In this sense, the use of BIM models can be understood as the simulation of construction and operational processes of a building (Barnes and Davies, 2014), rather than an abstraction of the materiality of a building expressed in a graphic representation.

The point is that, as a digital model of the building, the resulting BIM model can provide visualisations and data to be extracted and analysed to inform further actions and decision-making in the construction industry (Barnes and Davies, 2014).

In this sense, the BIM as an approach potentially supports a digital coordination for design and construction team, as an anticipation of the actual construction (Garber, 2014), offering the opportunity to achieve it by a systematic coordination and use of all data available (Barnes and Davies, 2014). Most of this coordination happens through the enhanced tri-dimensional visualisations, which according to Garber (2014) allows the examination of a great amount of design characteristics at the very beginning of the process.

Analysing the essence of BIM systems, Akin (2014) argues that those systems aim to provide the technological support to some of the fundamental aspects of management in the AEC environment, mostly regarding the need for coordination of large data repositories, intra-task collaboration and smart representations. In specific to the design process, the BIM systems produce a shared information model linking three-dimensional geometry with real-time databases, which is a completely different from the traditional approach to computer-aided drafting (CAD) systems that simply allowed documentation to be drawn in the computer.

BIM can be recognised as a technological advance that changes not only the construction delivery process considering efficiency and coordination, but definitively the design process as well (Garber, 2014) mainly affecting how designers conceive the design in a structured and collectively way.

The introduction of BIM brings an inherent duality under the ideal concept of shared information models, where the architects are supposed to still act as the creative director (the author) as well as the supervisor of a collaborative team of experts that are sharing ideas and responsibilities, in the collective production of the design (Garber, 2014).

However, successful collaboration is not only product of the adoption of BIM software, and even the ability to build virtual models of construction project does not instantaneously produces maximum efficiency (Kocaturk and Kiviniemi, 2013). The information needed in the processes must be correctly understood, and it means to model and share properly the design representations, as well as to assure a robust technical infrastructure and a proper business model (Kocaturk and Kiviniemi, 2013), which indicates the necessity to engage in an integrated delivery process.

DESIGN ONTOLOGY AND BIM APPLICATIONS

Knowledge-based structure applications

The virtual modelling operations involved in BIM technology does no longer can be understood as the representational process which we are familiar with, because differently the virtual building information model is, within computer software, a completely built entity waiting to become physical (Garber, 2014).

One of the major aspects of BIM as new media for design production (creation and communication) relies on its knowledge-based structure. According to Sheward and Eastman (2014), this refers to the ability of BIM applications to carry/input/manage design knowledge information. In this sense, these authors suggests that design rules, parametric constraints and parametric objects are the structure/scheme in which this information is made explicit.

The alignment of BIM applications with architectural design knowledge seems to indicate a consistent approach to BIM adoption. In artificial intelligence research, software are usually seen as a structure to formalize and store knowledge (Clayton, 2014). Using this premise, Clayton (2014) suggest that BIM applications can be addressed as a compendium of architectural theory assisting and guiding designers in architecture discipline. This understanding on the nature of BIM applications, proposes that BIM tools expertise is inextricably linked to the core architectural knowledge related to theory and meaning in architecture (Clayton, 2014).

Therefore, the development of BIM skills for professionals would start with Architectural Knowledge, as well as for students BIM applications would play an important role to make the architectural knowledge both explicit and actionable, providing support to knowledge retention and also allowing it be incorporated into design behaviour (Clayton, 2014).

It is important to understand that Architectural knowledge usually can be correlated to the input of intelligent data in BIM models, in example, Barnes and Davies (2014) suggest that design criteria, detailed specifications or performance criteria, are the main kind of intelligent data embedded in BIM models.

This kind of data is embedded as a geometric object-oriented representation of project making the model ‘intelligent’ or interactive (Barnes and Davies, 2014). When the interactive data can affect the geometry of the symbol, it is recognised as a ‘parameter’ and the symbol a ‘parametric’ entity (Barnes and Davies, 2014).

Considering that BIM applications were built based on a whole system of relationships that works to structure and articulate those symbols in the virtual environment. The strength of a parametric building models relies on the establishment of a network of relationships among and between all these symbols (pieces of the building), in such a connected way that if any detail of the building is changed all the rest will be affected and automatically changed (Barnes and Davies, 2014). This is what these authors call associativity, which is a defining feature of true BIM models.

It is possible to agree that the establishment of those relationships in a building model are the essence of architectural design of a building (Barnes and Davies, 2014). According to the same authors, this is a natural and intuitive way of thinking about buildings using a computer, in which the use of parametric modelling allows designers to directly access these fundamental relationships, in the same way as a spreadsheet is a tool for thinking about numbers, or a word processor is a tool for thinking about words.

It can also be argue that this would assist designers, as long as BIM applications usually provide pre-programmed definition for the symbols and how they operate and interact with the role system (Barnes and Davies, 2014). Therefore, according to these authors, a parametric building model is based on the combination of a design model and a behavioural model.

A new pattern of thinking: Parametric Thinking

In comparison with conventional design, parametric design is different because it provides a new design tool and also a new way of thinking (Yu et al., 2015).

Yu et al. (2015) conducted an empirical study with eight professional architects with relatively experience in parametric design. Based on a protocol analysis the study suggested that in a Parametric Design Environment (PDE) designers do not only design by applying design knowledge, but they do use parameters defining rules and their logical relationships. According to Yu et al. (2015) this indicates that they are not only thinking about the actual building design, what can be called design knowledge, but also the rule design as a mechanism to achieve the building design, which can be called rule algorithm. Those authors support that these are the two classes of cognitive activities involved in a parametric design process.

While the design knowledge class address directly the design problem regarding shape and functional features of space been conceived, the rule algorithm class is used by the architect to operate the parametric design tool, defining rules and their logical relationships (Yu et al., 2015)

The results suggests that designers tend to focus more on design knowledge at beginning of design task, and then gradually move to a predominance of parametric scripting (Yu et al., 2015). With this results, the researchers implies that designers are substituting rule algorithm for design knowledge. Most importantly, this indicates design patterns can be encoded to form the basis of reusable rules that could allow a designer to develop a style of designing (Yu et al., 2015).

This finding also indicates that architecture education should focus more on the concept of parametric design in general, it means how design knowledge is connected to the rule algorithm (Yu et al., 2015). Another important argument, is that this design knowledge/intelligence that is inherent in building information models is key to foster collaboration between those on the design team and those who build the design itself (Garber, 2014).

It is possible to recognize as an effort to make this design knowledge structured and shareable in the development of a product model standard. The International Alliance for Interoperability (1996) has been working to develop the Industry Foundation Classes (IFC), which allows different applications to share Building Information Models and consequently it promote a direct use of data for different purposes (Kiviniemi and Fischer, 2009).

However, it is superficial and unsustainable to consider BIM solely as a piece of software (Kocaturk and Kiviniemi, 2013). According to Kocaturk and Kiviniemi (2013), the principles embedded on BIM systems that should be considered in the architectural curriculum are the basic concepts of an integrated design and project delivery. Most importantly they are intrinsically linked with architecture design knowledge.

THE EVOLUTION OF DESIGN KNOWLEDGE AND SKILLS

To better understand the impact of building information modelling on design cognition it is important to look back how the ancient master builder originated the modern figure of the architect, after the repositioning of architecture as a discipline under an unstoppable movement towards the engagement with technology.

The master builder, the pre-renaissance idea of the architect, was the one responsible for the holistic process of creating a building, binding design and construction together (Garber, 2014). Then, during the Renaissance, architecture practice was codified, moving it far from the professional classifications of the Middle Ages, and started to be treated in the humanistic culture, as a set of individual talent against its collective traditions (Benevolo, 2012 apud Garber, 2014).

The technological aspect of this movement that eventually supported this epistemological realignment of architecture knowledge, was pointed out by Garber

(2014) mentioning that the advent of the printing press in Italy in that period allowed for the broad dissemination of architects' working methods, as well as the contemporary methods of construction, as new "package" of information inside the books.

From this moment, architectural education moved from the secretive basis of the guilds to an approximation of what now are the accredited programmes of the architecture (Garber, 2014). This represented the repositioning of architects far from the building site, which in the other hand allowed them to work remotely, focusing in the development of the design (Garber, 2014).

The separation from the building site made the renaissance architect to rely on models as a way to ensure a three-dimensional understanding of the scope of the work (Garber, 2014). Those models use to be a result of a collaborative effort from designers and small groups of craftsmen, masons or woodworkers, who would then be responsible for the actual construction (Garber, 2014). Indicating the collective nature of producing models in the ancient period.

Another important issue addressed by Garber (2014) is that while before the master builders would get experience from technical training in the guilds, like an apprenticeship, nowadays generally the younger and less experienced designer-builders is the one who have more experience with the technological tool. This situation produced a gap that is generally filled by BIM manager, which would be responsible for the integration of digital content. However, this could be a weak link in the design communication since the BIM manager does not necessarily need to understand how to build (Garber, 2014).

According to Garber (2014) the younger practitioner may acquire the necessary expertise in a virtual manner, putting the idea of information modelling as a new combination of experience and data in the development of design scheme, what he called "pre-modern intuition".

Architectural knowledge: the necessity of a sharable ontology

On the other hand, the current discussion on the nature of architecture knowledge relies on the concept of a basic sharable ontology that would include a taxonomy and its respective relations to each other defining coherent semantics (Clayton, 2014).

The relevance of this discussion is fundamental, considering that every BIM software system provide a collection of commands based on an ontology system, that make the connections between the abstract structure of computational data and the concrete domain knowledge of a practical building task (Clayton, 2014).

Usually the architectural ontology used by BIM systems to define a shelter tend to be direct and unpretentious (Clayton, 2014). One of the main things that distinguished BIM from CAD systems, is the incorporation and enforcement of architectonic relations that are also ontological (Clayton, 2014). This is the basis for how BIM systems incorporate behaviour (functional performance) to objects corresponding to real world expectations. There are correlations between the parameters, or special non graphic fields, with specific software routines to model our expectations from the real world (Clayton, 2014), in other words, the ontology is the route for parametrization and also software simulations.

All these concepts of an architectural ontology may not be so obvious for architecture students and others learning BIM, which demands this ontology to be explicit rather than solely tacit (Clayton, 2014). This indicates that, maybe the first step on this changing process should be a discussion of architectural ontology in conjunction with basic BIM command as way to understand the associated meanings and expressions with architecture materiality (Clayton, 2014).

Fundamentally this systems introduce a paradigm shift in the architectural production and delivery process, in which the design used to be understood as a transformation process from the possible to real, and now in BIM systems it produce a more integrated move from the virtual to actual (Garber, 2014).

Parametric modelling is based on constraint modelling, in which a range of dimensions or other parameters are used to allow design variations (Clayton, 2014). This is possible because the relations among geometric elements are explicitly defined, and variations are ruled by a specific formula that the input can be varied systematically or randomly generating new designs (Clayton, 2014).

In this new paradigm design goals and their respective optimisation through simulation are established by the diagram and constraint geometry (Garber, 2014). Potentially this simulation allows at the earlier level of schematic design to develop the relationship between energy efficiency, and structure and programming (Garber, 2014).

The current limitations of BIM as medium for architecture design indicates the need for further development on formalizing and making explicit architectural theory (Clayton, 2014). This can affect both the experienced architect, in which the concepts expressed in BIM can be demystified by the familiarity and comfort of regular use of architecture theory, and the student, in which the discussion of architectural theory can help BIM concepts to be more connected and approachable to education (Clayton, 2014).

THE CORE CHALLENGES TO ADOPTION

Considering that design expertise is something build through years of practical experience and effective learning from problem solving situations, the majority of organizations in AEC face the challenge of transferring the individual expertise knowledge in design to the whole organisation and to retro feed the design process within the company (Sheward and Eastman, 2014).

Usually this design expertise is transferred in a mentorship system, which tries to capture and formalise design expertise and generate design guidelines or best-practice compilations (Sheward and Eastman, 2014). According to these authors this process is limited to the capability of novel designers to learn and apply those design heuristics effectively.

In this context, Sheward and Eastman (2014) support that a wide range of types of design expertise can be potentially embedded on contemporary BIM tools. The formalization and rationalization of design heuristic can be structured in BIM systems as a platform to gathering features such parametric modelling, object relational databases and application programming interfaces (Sheward and Eastman, 2014).

However, a key point is the management of the acceptance of the new technology. According to Kiviniemi and Fischer (2009) the difference of drafting and designing using computers software, relies on the fact that while the use of a pen does not demand any conscious thinking, the user-interface of CAD program, in the other hand, are usually complex and demands significant time and effort to learn sufficient skill level. Kiviniemi and Fischer (2009) agree that it is important to discuss how this technology affects the design process under two perspectives: the sketching, in which relates to the internal thinking process of generating a design solution, and the documentation, which is recognized as an external communication process.

In both processes design tools act like media providing the means (language and structure) to create communication, in one case to the internal reflective process and the other one with the other stakeholders in the building delivery process.

Those early sketches, as a type of media to produce “visual thinking” do not represent the usual projection type, as a technical representation of construction (Kiviniemi and Fischer, 2009). In this sense, these authors support that, no matter what the architecture style and design methods used are, the design media which will support the creative process must be based on a hand-eye-brain instinctive interaction. Kiviniemi and Fischer (2009) argue that the creative process demands high level of concentration and any necessity to think about the tool or its interface can be considered as a disruption on the thinking process.

Considering that the process of abstract sketching and diagramming is in the base on how architectural concept are developed (Laseau, 1986), those diagrams must embrace a particular graphic language that encode semantics into line weight, line style, colour, shape and other attributes (Clayton, 2014).

While BIM tools substitute the process of drafting, drawing and diagramming by allowing the definition of rules to generate the graphics, it is regarded to the designer to establish/choose the graphic conventions which will be set to focus attention on a specific aspect of the design (Clayton, 2014).

Clayton (2014) indicates that this diagramming method mediated by BIM tools definitively disrupt the graphic thinking that was the original intention of diagramming. However, it can be argued that this method allow architects to think more strict about semantic intentions of design, while the computer will be responsible to produce the realisation of that in a rigorous diagram (Clayton, 2014).

The second aspect of communication in design is related to how designers engage the other projects stakeholders in the building delivery process. At this point the designer’s concern is to produce data to inform specific actions, which includes much more details than the previous sketches. In this context, construction drawings are highly regulated and represent a formal language with their own syntax and semantics (Kiviniemi and Fischer, 2009).

Kiviniemi and Fischer (2009) indicates that computer applications have been evolving to solve the problem of fragmented information and they have been working to provide new possibilities to manage data through the concept of BIM.

For a long period of time, drawings have been recognised as the most effective media to exchange information needed in the process as all AEC professionals understand the drawings immediately (Kiviniemi and Fischer, 2009). In this sense, BIM tools offers opportunity to flexibly choose the view of the virtual model (Kiviniemi and Fischer, 2009), and then actively extract the information needed.

The influence of tools on the way designers think has never been so significant and variable, mostly because these ubiquitous mediating structures generate a new social organization that is not only concerned with tools and new forms of representation (Kocaturk et. al., 2012), in other words it demands a new pattern of collective thinking (cognition).

The context of architecture learning is shifting from an approach based on the individual development of the designer to a more comprehensive and collective system of integrated individuals in a situated, tool-mediated and socio-technical context (Kocaturk et. al., 2012). Innovative practices are recognising the importance of establishing innovative mechanisms, along with design technologies, to structure and coordinate multidisciplinary intelligence (knowledge) through various media and organisational structures (Kocaturk and Medjdoub, 2011).

The process to make available and to coordinate the tools and ideas from different disciplines, is the basic concept to foster the distribution of ´design-knowledge´ (Kocaturk and Medjdoub, 2011). Those authors refers to this multitude of interdisciplinary design knowledge as the basis for the distributed intelligence, in which the background, experience, media and specific technologies of different individuals support their thinking, the communication and the social network with the group.

The emergence of a dominant form of cognition, called “distributed cognition”, based on a contextual, ‘social shared’ and ‘tool-aided’ approach, in which the resources that shape and enable activities are distributed among people, environments, situations and artefacts (tools) (Kocaturk et al., 2012).

Introducing such approach represents a major disruption from traditional design educational models, in which “design cognition” has been perceived as an internal and individual process on designer’s mind that should be individually developed (Kocaturk et al., 2012). According to these authors, today one of the major pedagogical challenge in architectural education relates to how to engage the concurrent and interconnected development of the individual and distributed levels of intelligence on students through diverse methods of knowledge acquisition and methods of delivery.

A new approach should aim not only on involve students as part of a context of “distributed intelligence”, but definitively to engage them in the collective creation of such intelligence in different contexts (Kocaturk et al., 2012).

Another limitation of old design methods that have been emphasized in many architectural schools is the development of a mental structure based on drawings, that may be an obstacle for students when they engage in tools that demands new ways of thinking (Kiviniemi and Fischer, 2009).

According to Akin (2014) some of the incompatibilities of BIM environments regarding the cognitive behaviour of designers relates with three main features of a regular design process: first, is that the designers create unique reassembles on design problems based on a self-defined criteria to filter information, and this are not necessarily in accordance with predefined sets embedded on BIM tools; secondly, BIM software systems usually do not support the designers exploration in a space of potential solution alternatives without relying on external memory aids. In this sense, designers generally engage in an unique process sequence in which they manipulate cognitive chunks of information that not necessarily match the predefined expertise-related assemblies in a BIM tool/system; And thirdly, as long as individual partial solutions demand some type of reassemble to generate a design alternative, current BIM software are unable to produce iterative integration between eventual concurrent solution sets.

CONCLUSION: SUPPORTING A NEW DESIGNING PARADIGM

BIM technology and digital design media are fundamentally changing the production and communication of design information, mainly because it introduces a separation between representation and content (Kocaturk and Kiviniemi, 2013). In this context, the focus moves from the nature of "drawing" to the notion of "modelling" an intelligent model of the design (Kocaturk and Kiviniemi, 2013).

Historically, this huge emphasis on "drawings" has consolidated the use of scales as means to establish a "layered thinking", which is a massive expression of the dominant Cartesian Thinking in architecture discipline (Kocaturk and Kiviniemi, 2013). In the other hand, these authors argues that, the very nature of modelling demands a holistic thinking of the product as a system.

Kocaturk and Kiviniemi (2013) propose that representations should be approached as means to design creation, development, coordination, communication and negotiation processes, and not to focus only in the representation of the final product. According to these authors, this could be achieved by discussing how are different ways of embedding value and information into design through different levels of abstractions and alternative types of representations considering the stakeholder and its purposes in the delivery process.

The replacement of construction documents and shop drawings by a new paradigm of design based on the concept of information modelling relies mainly on how designers deal with abstraction (Garber, 2014). Abstraction plays an important role in designing, since designers regularly use abstraction to organise internal relationships of project without being "restricted" by the material reality of buildings at the beginning of design (Garber, 2014).

Since information modelling consist in the virtual anticipation of what is to become real, the development of the information model indicates that the relationships between building components in the model are becoming less abstract (Garber, 2014). In this context, those potential relationships within a model are materialised by diagramming, which can be recognised as useful device to check the comprehensive structure of an information model (Garber, 2014).

Assuming that the introduction of BIM technology in the architectural curriculum will directly affect two major topics: one is the collective nature of project delivery, considering how designers and other stakeholders should collaborate; and the other refers to how to model, embed and share information take into account the whole lifecycle of buildings (Kocaturk and Kiviniemi, 2013).

This study finally proposes that, in this paradigm shift in architectural professional training, diagramming should be repositioned as a thinking tool to support a systems thinking required to connect a knowledge-based structure with smart data embedded in BIM applications. The use of diagrams based on a common ontology would be the way to provide a natural progression to thinking process on designing moving from abstract concepts to concrete materiality in buildings design in a shareable multidisciplinary context.

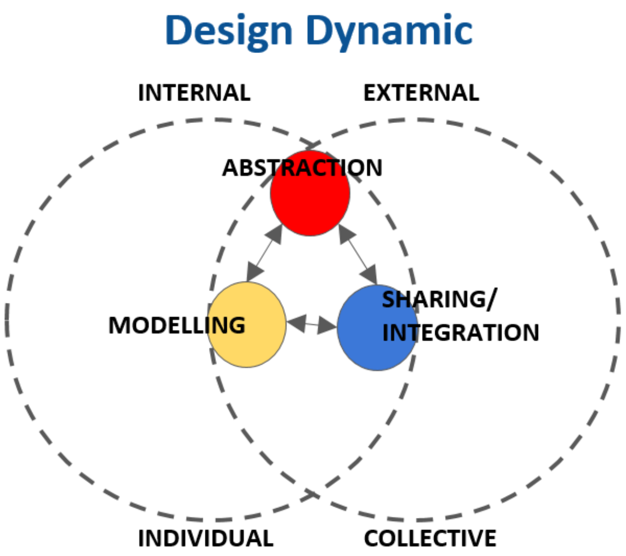

Figure 1: Design Dynamic model of collaborative cognition

The act of diagramming would allow the collective development of the functional relationships between concepts and then preserve those fundamentals relationships between building components based on the common ontology in a parametric application.

There are already some software products providing such connection between diagramming and BIM applications, i.e. the Dynamo developed by Autodesk ®. However, it is essential that the adoption of such tools would be carried in a learning context. The introduction of "BIM and integrated design" concepts should be gradual and progressive, in which the new technology and new method must be put into context and connected with the rest of the curriculum in a way that it should be possible to the student to reasonably identify how it indicates an evolution from previous tools and working methods (Kocaturk and Kiviniemi, 2013).

The next step on this research will conduct an exploratory study on architecture students and experienced designers to identify how much architects are aware of the connectedness nature of architecture knowledge (ontology) and how this have been addressed in current design tools. The results could give some directions on how diagramming would be a powerful framework to support design thinking on this technological disruption on design practice.

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CONSTRUCTION EDUCATION REQUIREMENTS FOR ACHIEVING LEVEL 2 AND 3 BIM

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The Architecture Engineering Construction (AEC) Industry is well noted for its fragmented nature, leading to several flaws in communication and information processing, which have led to a proliferation of adversarial relationships amongst project participants, thereby affecting the integrity of design information throughout the project life cycle. Likewise, Construction Education is bedevilled by multitudinous issues due to its practice-based, interdisciplinary nature of the industry, its professional and institutional history, and its evolving context and composition. These challenges have influenced the purpose of construction as well as the requirements or strategies needed to achieve it. The purpose of this paper is to examine the nature of Construction Education and learning requirements for successful training and implementation of Level 2 (with the aid of a process map) and also of Level 3, to meeting the ever-changing nature of the AEC industry. This process map seeks to identify the educational requirements for existing industry practitioners and for fresh graduates entering into the industry. In order to achieve this aim, a case study methodology was adopted using semi-structured interviews with BIM experts in purposively selected organisations in the UK, which were further analysed using single case narrative and cross-case synthesis techniques. The BIM sub-processes at each project phase of the construction process were extracted from the interviews conducted. Then the process map linking all the BIM activities in the project was developed. In conclusion, the process map formalises the knowledge and skills set required to successfully implement Level 2 and 3 BIM, facilitating project collaboration, communication flow and agreement amongst project participants on construction processes throughout the project lifecycle. The finding of this research are highly aligned with the seminal literature which argued that new skills required for the creation and management of a BIM model fall into the three categories of technological tools, organisational processes, and project team roles and responsibilities, and that these three skill sets contribute to the success of the entire BIM project and adoption in any organisation.

Keywords: Construction Education, Learning Requirements, BIM Learning Outcomes, Level 2 BIM, Level 3 BIM, UK AEC Industry.

INTRODUCTION – THE NEED FOR CONSTRUCTION EDUCATION

The Architecture Engineering Construction (AEC) industry is well noted for its fragmented nature, leading to several documented flaws in communication and information processing (Latham, 1994; Egan, 1998). These flaws have led to a proliferation of adversarial relationships amongst project participants (Forcade et al., 2007; Gudiene et al., 2013), thereby affecting the integrity of design information

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throughout the project life cycle (Cera et al., 2002; Fruchter, 1998). Business organisations such as AEC organisations are constantly reinventing ways of thriving in a highly competitive business environment.

In a similar vein, construction education is bedevilled by multitudinous issues due to its practice-based, interdisciplinary nature of the industry, its professional and institutional history, and its evolving context and composition. These challenges have influenced the purpose of construction as well as the requirements or strategies needed to achieve it. One of the key drivers of change in construction education practice is the advent of BIM and other aspects of digital construction, which has essentially transformed every segment of the AEC industry, including the roles, responsibilities and inter-relationships between the players acting in the construction world.

According to Camps (2008), the same concepts that seek to transform the AEC industry are also beckoning for change in educational strategies in the academia; and that academic institutions play an essential role in the overall success of BIM implementation in the entire AEC industry. Camps (2008) also stressed that for professionals to be capable of doing more in less time, construction education has to become more efficient in training students who eventually become those professionals. Adding that, for a large-scale integrated practice to be attainable within the AEC industry, adoption of BIM education in the classroom must come first. In accordance to these, the purpose of this research was to examine the nature of construction education and learning requirements for successful training and implementation of Level 2 (with the aid of a process map), to meeting the ever-changing nature of the AEC industry.

LITERATURE REVIEW

Current State of Building Information Modelling Education

BIM enables educators, professionals, and students alike, to explore projects more in-depth than ever before because a single model can be used to produce construction documents, examine constructability, estimate project cost, investigate building performance, and build physical models with the aid of state-of-the-art prototyping (Camps, 2008). According to Camps (2008), much of the industry still operates a paper-based management system steeped in a 2D paradigm, suggesting that BIM educators need to examine this matrix closely, and break out of the mould. Kymmell (2008) posits that most barriers to the uptake of BIM in the academic curriculum are due to: a lack of understanding of the BIM process, instability to use the required BIM tools for specific BIM tasks, and circumstantial issues such as the conduciveness of the environment, participants of the process, experience of the teaching faculty, training budget, etc. However, Hietanen and Drogemuller (2008) highlighted that the barriers relating to a lack of understanding of the BIM process demand greater attention than the others because, in their view, an understanding of the idea is more essential than the mastery of the required tool.

Some educational institutions such as Coventry University, California State University (Chico), Pennsylvania State University, to name a few, have overcome some of these hurdles, and are now regarded as leaders in BIM education by perfecting the synergy and coordination of three levels: teachers, curriculum and university (Hietanen and Drogemuller, 2008), achieving remarkable feats in BIM pedagogy. However, Barison and Santos (2010) noted that educational institutions planning to embark on BIM education will encounter many problems; the greatest of which will be institutional, which entails promoting integration within different curriculum aspects and collaborating with other departments or schools to promote integration. This lends credence to Kymmel's (2008) conclusion that Collaboration is a foundational concept to the entire BIM process, which encourages a learning team to become a cohesive team, overcome hurdles, and make progress together.

Many national governments have established BIM as a necessary requirement in the AEC industry (Zeiss, 2013), which has created an urgent need for educators in the industry to train BIM-ready graduates in order to meet industry requirements globally (Rooney, 2014). Hence, Hon et al. (2015) considers it highly imperative for educational institutions to incorporate BIM into their curricula, and also reinforce the capacity of BIM educators to cope with the change, as Sacks and Pikas (2013) found out in their study that a lack of competent BIM educators is an undeniable barrier for incorporating BIM in education.

Hon et al. (2015) conducted a literature review on BIM education dating back to ten years; the outcome of which forms the fundamental basis to identify gaps in current learning and teaching methods, which will help in the adjustment of the modules or curricula. The research reveals that six core aspects of BIM learning and teaching were selected by authors, namely: 1) Essential BIM skills 2) Integration Strategies 3) Teaching Methods 4) Assessment Criteria 5) Assessment Methods, and 6) Critical Success Factors in BIM education. However, Hon et al. (2015), out of the six aspects of BIM learning and teaching, pointed out 3 under-explored areas to be: Assessment Criteria, Assessment Methods, and Critical Success Factors for BIM education.

In conclusion, Sacks and Pikas (2013) emphasised that BIM is a holistic process that must be introduced into curricula in a methodical manner such as being taught as standalone courses or incorporated into existing courses. However, each education provider will have to make decisions of where and how to introduce BIM, with regards to their unique context, policies and strategies.

Building Information Modelling Level 2 and Level 3

The UK Government's decision to mandate Level 2 BIM for publicly procured projects by 2016 appears to address the fragmentation and complexity of the AEC Industry (Latham, 1994; Egan, 1998; Cabinet Office, 2011; Charalambous, et al. 2013). There are signs indicating that many AEC Organisations have come to acknowledge the value in adopting BIM technology, and seeking to define their role within the BIM process (Waterhouse and Philp, 2013). In 2013, the UK Government published another report, Construction 2025, setting out its long-term vision to place UK at the forefront of global construction and market. To drive this vision, the UK Government is willing to invest in smart construction and digital design by investing in people and technology, in collaboration with the AEC Industry. The UK Government and the Industry have successfully developed an effective BIM strategy, and HM Government (2013) reiterates that only through BIM adoption will more sustainable buildings be delivered more quickly and more efficiently, such that lower project costs, lower carbon emissions, faster project delivery and improvement in construction exports are achievable.

Despite the widely acclaimed benefits of Level 2 BIM, the most significant change will emerge by the adoption of Level 3 BIM (BSI, 2014). Charalambous et al. (2013) affirmed that Level 3 BIM represents a paradigm shift in the re-engineering of the process and mindset of the industry. The gap between the current BIM situation in the UK and the 2016 mandate is gradually being bridged as some AEC organisations are nearly attaining the goal, hence the need to take BIM adoption to the next level of maturity, which is 'BIM in the Cloud'.

The BIM Task Group, a Government body that drives BIM implementation on public sector AEC projects across the UK, developed a model called the BIM Maturity Model (BIM Industry Working Group, 2011). According to BIM Task Group (2013), the Maturity Model explains maturity levels with respect to the capacity of the AEC supply chain to manage and exchange project information. The model's application spans a wide spectrum of project scenarios, such that a particular organisation may have several projects operated at different levels of BIM Maturity, which is normal and anticipated, as different organisations attain maturity at different timescales, based on a number of factors.

NBS (2014) noted that the UK Government acknowledged the fact that the process of moving the AEC Industry to full collaborative platform will be a gradual process, with milestones recognised as 'levels', which range from Level 1 to 3. Hence, the BIM Levels of Maturity are expatiated below:

NBS (2014) and DBS (2015b) explain that the Level 1 BIM is a combination of 2D for drafting of approval documentation and Production Information, and 3D CAD for concept work. The CAD standards adhere strictly to BS1192:2007; and the Common Data Environment (CDE) often managed by the Contractor, is used to share data electronically. Majority of AEC organisations in the UK are operating at this level, whereby each project participants publish and maintain its own data without any collaboration with other participants.

At the Level 2 BIM, NBS (2014), DBS (2015b), and Goulding et al. (2014) maintain that all participants utilise their own 3D CAD models, enabling 2D/3D coordination based on BS1192:2007, but not effectively working from or with a single shareable model. Collaboration is achieved in the way information is exchanged between project participants. For example, design information is exchanged via a common file format, which allows parties to combine the sent data with their own data to facilitate a federated BIM model, and to carry out investigative checks on the model. In essence, the CAD software that each party deploys must be able to export to either of IFC (Industry Foundation Classes) or COBiE (Construction Operations Building Information Exchange) common file formats.

Attainment of the Level 3 BIM is seen as the 'holy grail', which symbolises full collaboration between all project parties with the facility of a single, shareable project model, held in a central location. All participants have access to this model and can modify it. The huge benefit is that it eliminates the potential risk of conflicting information. Also known as 'Open BIM', the UK Government has set a target date for public sector adoption by 2025 (HM Government, 2013). Issues pertaining to copyright are going to be resolved through comprehensive appointment of documents and software authorship – read – write permissions; issues pertaining to liability are going to be resolved through shared-risk procurement routes such as partnering, both facilitated by the Construction Industry Council (CIC) BIM Protocol (NBS, 2014; DBS, 2015b).

For the purpose of this paper, Isikdag and Underwood's (2010) definition is most appropriate, defining BIM as the information management process spanning the life cycle of a building, with focus on the collaborative use of semantically rich 3D models. These models contain rich geometric and semantic information about a project, where several views could be extracted from depending on the pressing business need (Goulding et al., 2014). Research has demonstrably shown that BIM is capable of revolutionising the AEC industry as a whole by improving project team collaboration (Gu and London, 2010); enhancing project integration (Woo et al., 2004); easing construction information flow (Ibrahim et al., 2004); enabling better documentation flow (Popov et al., 2006); supporting the facility management phase by decreasing operational cost (Wang et al., 2013); and generating simulation for construction sequencing, planning, clash detection and coordination interfacing (Fisher and Kunz, 2004). The Government task group mandated to drive change agenda in construction in the UK, Constructing Excellence (CE), clamour for the establishment of a framework for BIM adoption. Interviews with AEC organisations revealed that the adoption of BIM is favourable in the sense of the competitive advantage it offers; and the role it plays in enhancing the construction process, and also facilitating an integrated working environment (Dawood and Iqbal, 2010; DBL, 2015a). According to Al-Shammari (2014), the Construction Industry Council (CIC) issued the BIM Protocol which is designed to stimulate collaboration between project parties to support Level 2 BIM projects, concluding that the CIC BIM Protocol is inappropriate in dealing with construction contracts involving advanced levels of BIM (beyond Level 2), which might undermine its use. Seminal literature, Gu and London (2011); Rezgui et al., (2011); BIM Task Group (2013); and Dassault Systemes (2014), asserted that this is not likely to occur except project information is simulated and managed throughout all phases of the project life cycle, with the aid of Level 3 BIM adoption.

The purpose of this paper is to examine the nature of Construction Education and learning requirements for successful training and implementation of Level 2 and 3 BIM (with the aid of a process map), to meeting the ever-changing nature of the AEC industry.

RESEARCH METHODOLOGY

Interview method was adopted for this research for the following reasons: in-depth information was easily obtainable; there was greater flexibility than the questionnaire method to rephrase questions for better clarity and information; non-response of interviewees was much lower, hence cases were controlled more easily; the interviewer had access to additional information about the interviewee's personal information and work environment that may greatly enrich the interpretation of results (Kothari, 2004). A case study design was adopted for this study because the focus of the research is to answer the "how" and "why" questions, and to cover contextual conditions relevant to the phenomenon in question (Yin, 2009). A multiple-case study was adopted for this research to enable the researcher to explore differences between and within cases. For this research work, a literal replication of 2 cases was required to achieve similar research outcomes (based on literature review) and to achieve a greater degree of certainty and validation of the research study. The target population for this research work are companies involved in architecture, engineering, project management, and construction, and who have had involvements in BIM project environments. The choice of respondents in these organisations was made in gathering relevant data because these BIM Experts were directly involved in the supply chain for the delivery of BIM-driven projects across the UK. The respondents were drawn from Construction Organisations in the North West and Central London regions of England. Since, it is practically impossible to collect data from all construction organisations or all professionals; the non-probabilistic sampling technique was used, also known as deliberate or purposive sampling. Hence, a sampling size of 2 Case Studies was purposively selected in the North West and Central London regions of England, which were later used to represent the research findings for the United Kingdom. Data was collected for this research via two main approaches namely, fieldwork and desk study. Fieldwork research involved gathering data from primary sources of data, in the form of case studies, questionnaires, action research, etc. Desk study research involved gathering data from an extensive review of literature such as textbooks, journals, conference proceedings, online materials, etc.

RESULTS

This section presents the case studies of Level 2 BIM adoption through the project phases of a construction development. A process map was derived from the case study interviews, and illustrated below in Fig. 1. The two case studies are presented below, followed by the process map. The section is presented according to the construction project phases, and Case Study 1 is coded as CS1, while Case Study 2 is coded as CS2.

Level 2 BIM Adoption at the Preparation Phase

CS1 does not implement BIM at the Preparation phase because it is a Construction Management organisation that usually takes up projects at the Construction phase and not at the Preparation phase. The CS2 respondent noted that the first thing the organisation does in the Preparation phase of BIM implementation is to hold an introductory BIM Project Execution Planning (BIM PEP or BEP) session comprising the key stakeholders contributing to the project depending on what stage the project is at. The planning sessions set out the project direction, project scope from BIM perspective. In CS2, BIM objectives are confirmed at the Preparation phase. CS2 pointed out that stakeholder roles and responsibility matrix is crucial in the Preparation phase in terms of who is going to be the point of contact for each task and information role. CS2 also discussed how stakeholders collaborate and coordinate information across the project so as to deliver the project outcome for the Client. Inputs like file exchange formats, classification standards, specification standards, etc., are used to enhance BIM project delivery and check project status. CS2 agrees with LR's BIM core activity, which includes definition of BIM inputs and outputs or deliverables, and extent of post-occupancy assessment (RIBA, 2012; Klaschka, 2014).

Level 2 BIM Adoption at the Design Phase

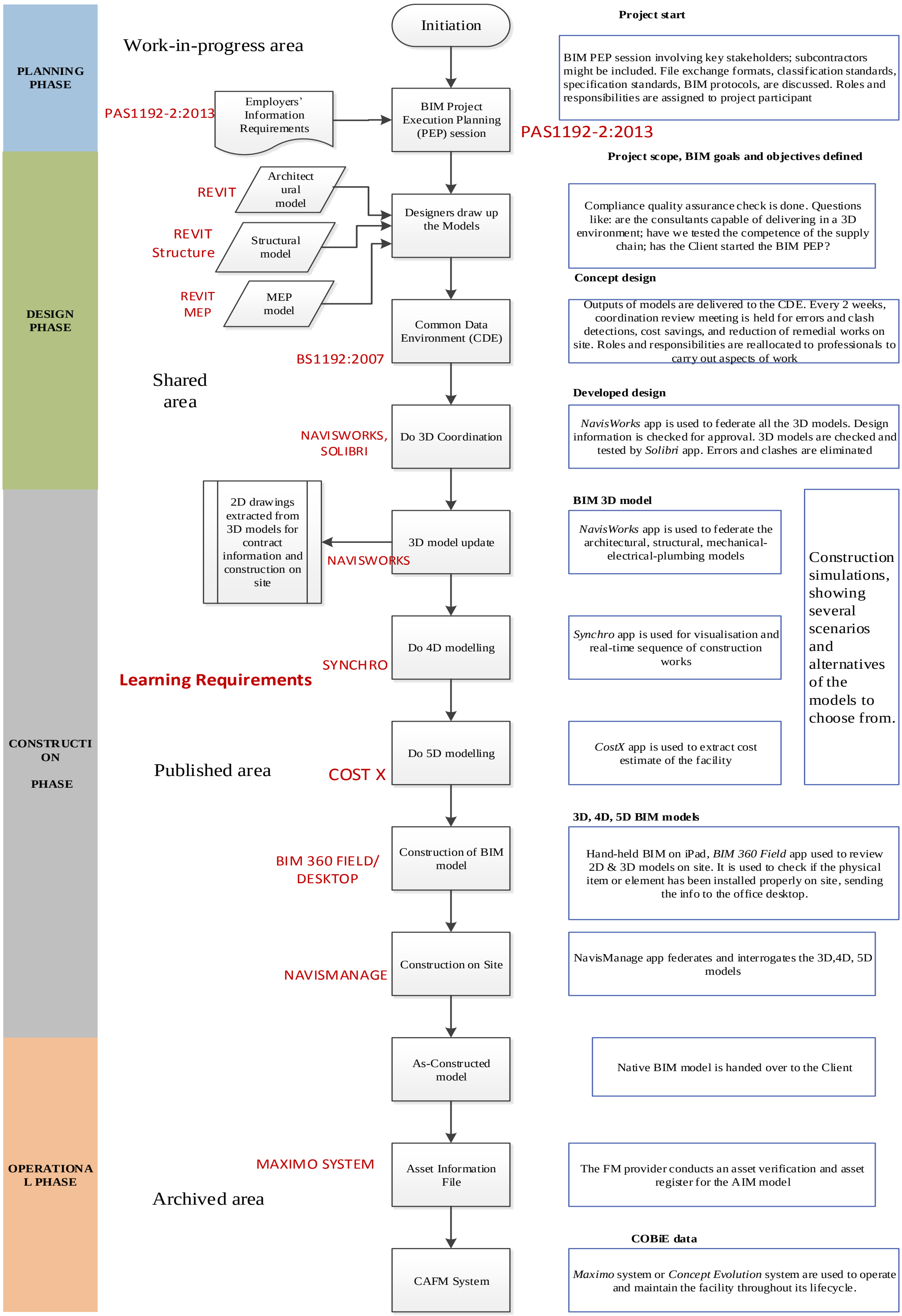
CS1 comes in at Stage 3 of the PAS 1192, which is the design phase. They implement the BIM PEP for post-contract obligation of the project, which is synonymous with the commencement of a BIM pre-start meeting on the agreement of BIM PEP and BIM Change Control Protocols. In CS1, designers draw up their models (architectural, structural, mechanical, electrical and plumbing) and upload into the Common Data Environment (CDE). CS1 reveals that there is a coordination review meeting, in which errors and clashes are discussed and resolved. For CS1, update contract 2D drawings are extracted from the 3D models, which are used for contract information and actual construction on site.

The CS2 respondent revealed that when their organisation receive design models at any stage, they need to understand if they are useful; they need to ask if the customer has provided any Employer's Information Requirement, or if the Customer has prescribed a BIM protocol, or if the Client has started the BIM PEP already. CS2 respondent affirmed that information needs to be transferred seamlessly through the project phases, stressing that it is complicated transferring knowledge and information, and ensuring every project participant is carried along; that is why the Common Data Environment is crucial for effective collaboration. CS2 respondent also pointed out that once they take up the Design and Build responsibility, they employ the designers (on behalf of the Client) and drive the design process to deliver the output.

Level 2 BIM Adoption at the Construction Phase

CS1 emphasised the use of Hand-held Field BIM device to review 2D drawings and 3D models on the construction site. The device is used to check if a physical item or element has been properly installed on site; working in conjunction with the office desktop to highlight and mark up drawings or aspects of models. CS1 and CS2 use the Synchro app for 4D visualisation to upload a model and visualise the time sequence of construction activities on site. CS1 and CS2 also use the Cost X app for quantification of building elements. In CS1, the BIM tools are used to model a building (then all the different models are federated together), and several meetings are held to discuss how the models will be installed and erected on site. After the construction of the building, CS1 confirms that the 3D model is handed over to the Client at completion. CS2 respondent confirmed that the use of BIM model for the fabrication of building components starts early in Stage 5 of the RIBA Plan of Work to maximise the benefit. Standardisation of the fabrication in terms of design, manufacture and assembly can be optimised using object libraries. CS2 confirms the use of BIM to discover design errors and omissions before actual construction; in the sense that BIM increases right first time delivery, by reducing defects and issues of coordination. It enables the firm to visualise several scenarios and mitigate risks before the model is actually built on site. CS2 confirms that it uses BIM to integrate design and construction planning. Also, CS2 uses BIM to integrate procurement strategy with design and construction. CS2 employs BIM to implement lean construction methods by delivering lean process across the full project lifecycle. CS2 also coordinates and releases BIM models at end of construction by producing the native model file and asset information file for release. On the use of BIM to clarify and resolve design queries as they emerge, CS2 confirmed that it could coordinate design and report data queries within minutes, rather than wait for 28 days of approval of a design query when one is made, which has a positive impact on project cost and schedule.

Fig. 1. Process Map Showing Level 2 Adoption through the Project Phases (Ojo, 2014)



Level 2 BIM Adoption at the Use/Operational Phase

Given that CS1 does not feature in the operational phase of BIM implementation, it does not use 6D or FM models. However, CS2 engages in the operational phase of BIM implementation. It runs a PAS 1192 – Part3 compliant process in line with the ISO 55001. CS2 affirms that BIM has reduced complexity such that they only need to maintain a 3D model environment linking it to an FM system so as to remain updated; this is how CS2 plans maintenance and react to maintenance issues at commissioning and handover. On the question of integrating BIM models with Facility Operation and Management System, CS2 stressed that only one or two contractors have been able to integrate BIM models with Facility Operation and Management System at any level, since different customer expectations mean different requirements. So CS2 is a work-in-progress as they try to do this properly in line with their internal asset management system. On the question of issuing Facility Management BIM model data as modifications in asset, CS2 explained that, in practice, the model data can only be maintained within the CAFM system, not within the BIM model. CS2 respondent further explained that one cannot use the BIM model to manage an asset, unless the native BIM model file is hosted on the CAFM system with hyperlinks to navigate through it.

DISCUSSIONS

The BIM functions or sub-processes at each project phases of the construction process were highlighted from the interviews. Then the generic process map above linking all the BIM activities in the project was developed. The information outputs at the end of each project stage were illustrated in the process map. The information inputs feeding into the BIM functions at the project phases were also examined from the interviews and illustrated in the Process Map.

In conclusion, the Process Map is one of the most appropriate ways to represent research findings in a process understandable to people working in an organisation, facilitating communication flow and agreement on construction processes. The Process Map above in Fig. 1 formalises the Learning Requirements for the adoption of Level 2 BIM in academic curricula.

Learning Requirements for Level 2 BIM Adoption at the Planning Phase

Kymmell (2008) defines learner as people who require training to learn and implement BIM processes such as students, educators and professionals. The following skills and knowledge are essential requirements for the training and implementation of Level 2 BIM in the industry:

1. The need to learn and understand the use of BIM Execution Plan (BEP) Guide, which is the starting point for BIM implementation.
2. The need to hold a collaborative BIM Execution Planning session with all stakeholders, clarifying project purpose, benefits, implications of BIM on project, stakeholder roles and responsibility matrix, file exchange formats, classification standards, specification standards, etc., to be used for the BIM lifecycle of the project.
3. The need to learn and familiarise oneself with the PAS 1192-2:2013 (The Specification for Information Management for the Capital/Delivery Phase of

Construction Projects using BIM, which specifies the requirements for achieving Level 2 BIM.

4. The PAS 1192-2:2013 proposes the creation of a BEP, which is used to manage the delivery of the project. Hence, learners should recognise and understand the critical steps to BIM Execution Planning in accordance with PAS 1192-2:2013.
5. The need for learners to understand the role of a supplier (as PAS 1192 defines it – a provider of services or goods either directly to the employer or to another supplier) because the pre-contract BEP is prepared by suppliers, trying to map out their approach, capability to meet the Employer’s Information Requirements (EIR).
6. The need for learners to understand the role of a supplier in meeting or responding to the EIR with the Pre-Contract BEP.
7. The need for learners to know and understand the role of a supplier in submitting a Post-Contract BIM Execution Plan, to the Client confirming his capabilities, including a Master Information Delivery Plan (MIDP).
8. The need for learners to appreciate what an MIDP is, and how project information is to be controlled and managed using the right protocols and procedures for each stage as the project proceeds (RIBA, 2012; Klaschka, 2014; Sinclair and Eynon, 2013, BIM Task Group, 2013b).

Learning Requirements for Level 2 BIM Adoption at the Design Phase

The following skills and knowledge are required to be provided through educational providers and institutions:

1. The skill to implement the MIDP during the post-contract obligation of the project is required.
2. The authoring skills needed to create architectural, structural, mechanical electrical plumbing (MEP) models are required learning for all BIM students, professionals and educators.
3. Capability of learners to deliver in a 3D environment.
4. Collaborative skills of consolidating all models together.
5. An overview of the Common Data Environment (CDE) using BS 1192:2007 as a guide foe effective collaboration.
6. The skill required to federate all the 3D models, architectural, structural, MEP, etc., with the use of NavisWorks app, facilitating BIM model sharing to enhance evaluation.
7. The skill required to check for clash detections of the 3D models with the aid of Solibri app, in a coordination meeting where clashes and errors are dicussed and resolved (RIBA, 2012; Klaschka, 2014; Sinclair and Eynon, 2013, BIM Task Group, 2013b).

Learning Requirements for Level 2 BIM Adoption at the Construction Phase

The following skills and knowledge are mandatory requirements for the education and implementation of Level 2 BIM in the industry:

1. The learner needs to be skilled in the use of applications such as Synchro app, for visualization and real-time sequencing of construction works, showing several scenarios and alternatives of the models to choose from.

2. The learner needs to be skilled in the use of applications such as CostX app, for quantification of building elements and cost estimate of the facility.
3. The learner needs to be skilled in the use of applications such as the Autodesk BIM360 Field app to monitor and review 2D and 3D models on site, and transmit the information to the office desktop.
4. The learner needs to upskill in the use of applications such as NavisManage to federate, coordinate and interrogate the 3D, 4D, 5D models for optimized project delivery on site (RIBA, 2012; Klaschka, 2014; Sinclair and Eynon, 2013, BIM Task Group, 2013b).

Learning Requirements for Level 2 BIM Adoption at the Operational Phase

There is a need to learn and understand the PAS 1192-Part 3 in conjunction with ISO 55001 to better appreciate BIM adoption at the use or operational phase. When the native model or as-constructed model is handed over to the Client, the Maximo system is used to operate and maintain the construction facility throughout its lifecycle. (RIBA, 2012; Klaschka, 2014; Sinclair and Eynon, 2013, BIM Task Group, 2013b).

Learning Requirements for Level 3 BIM Adoption

Looking ahead, the widespread adoption of Level 3 in the near-future will necessitate the following skills and knowledge for incorporation into academic curricula and industry at large. There will be a need for an awareness of the following:

1. Industry Foundation Classes (Data Definitions)
2. Integration and Standards supporting the Internet of Things
3. Unified Modelling Language Tools, to provide simplified technical and user data user access.
4. Model View Definitions
5. Process Definitions
6. Dictionaries and Ontologies
7. Data and transaction provenance.
8. Geospatial specific open data considerations
9. Internationalisation tools, etc. (HM Government, 2015).

CONCLUSION

Construction Education is bedevilled by multitudinous issues due to its practice-based, interdisciplinary nature of the industry, its professional and institutional history, and its evolving context and composition. These challenges have influenced the purpose of construction as well as the requirements or strategies needed to achieve it. It has been emphasised that BIM is a holistic process that must be introduced into curricula in a methodical manner such as being taught as standalone courses or incorporated into existing courses. However, each education provider will have to make decisions of where and how to introduce BIM, with regards to their unique context, policies and strategies. The purpose of this paper was to examine the nature of Construction Education and learning requirements for successful training and implementation of Level 2 and 3 BIM, to meeting the ever-changing nature of the AEC industry. A process map was deployed to illustrate the skill sets and knowledge required for the adoption of Level 2 and 3 BIM for students, educators and industry practitioners. These skills and knowledge can be used to formulate BIM-focused curricula to produce BIM-ready graduates and meet the needs of the AEC industry in the United Kingdom.

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CONSTRUCTION LEARNING AND EDUCATION: EXPLORING SYNERGIES THROUGH HOLISTIC REFLECTION

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Construction skills development programmes traditionally focus on the development of technical skills and knowledge to varying degrees and proportions. These approaches usually involve the cognitive dimensions of human learning to maximise effectiveness. However, modern learning theory postulates that individual learning is a holistic process of adaptation to views and contexts, where competence is made up of more than mere knowledge and skills per se. For example, an individual's mental energy, feelings and motivations should be conducive for learning and performance. Additionally, individuals need abilities for interacting with people, materials and the society in order to adequately learn from and contribute to their context/environment. These dynamics include such issues as 'emotional intelligence', 'organisational learning' and 'pedagogy'. This research presents empirically determined cognitive, emotional and social skill sets required for effective learning and optimal performance. This extends the understanding of success factors for effective learning and optimal performance within the construction environment.

Keywords: pedagogy; education; learning; performance, construction industry, training.

INTRODUCTION

Education generally may be defined as "the sum total of one's learning experiences during a lifetime. It is the total process of human learning by which knowledge is imparted, faculties trained and skills developed." This definition of education which recognises the integrated nature of knowledge and action is fairly modern (Ellis, Cogan & Howey, 1986, p. 134). The meaning of education has traversed from the traditional view of its being the process by which the older generation passes unto the next generation that which it considers to be true and valuable; through the stage where it was considered a process that produces a positive change in behaviour to the stage where it is believed to be fundamentally cognitive. Education has at some time been understood as something that goes on within institutional environments and is targeted at children and young people. Education was also considered academic in contrast to training which was considered skill based. Modern thinking does not distinguish between education and training, where they take place and at what age. All are seen as subsets of "learning" which is a lifelong experience; with cognitive, emotional and social dimensions; and can take place within formal, non-formal and informal environments. (Kolb, 1984; Illeris, 2002; Jarvis et al, 2003)

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Learning Theories

Learning theories underpin the methods of learning and teaching in most subject areas (Pugsley, 2011). Behaviourism has its origins in the work of theorists such as Pavlov, Watson and Skinner; and focuses on observable and measurable behaviour (Boghossian, 2006; Pugsley, 2011). Behaviourism sees knowledge as empirically determined fact only and is strongly influenced by positivist views and positions. The mental processes of the learner are not given consideration since inner processes are not measurable by available scientific procedures (Hung, 2001). Competency-based systems of education and training have their origins in behaviourism.

Cognitivism as a learning theory can be traced back to the early twentieth century and grew out of dissatisfaction with behaviourist tradition's failure to explain mental processes (Yilmaz, 2011). The work of theorists such as Tolman, Piaget, Vygotsky and Bruner instigated the dramatic shift from behaviourism to cognitivism. The cognitivist school views learning as an active process involving the acquisition or reorganisation of the cognitive structures by which human beings process and store knowledge. Methodologically, cognitivism adopts a positivist approach; its foundations are objectivist; and as with behaviourism, knowledge was initially considered to be distinct and abstract (Hung, 2001).

Constructivism as a learning paradigm is viewed by some theorists as a cognitive perspective to learning with the distinction of holding at its core the concepts that: knowledge is constructed by the learner and developed through experience (Kerka, 1997, Bush, 2006); there is no knowledge independent of the meaning constructed by the learner or community of learners (Boghassian, 2006); and learning is situated within the constructivism philosophical school of thought. Most traditional classroom based methods of learning and teaching are based on the cognitivist and constructivist learning theories (Pugsley, 2011). Constructivism though grounded in the work of theorists such as Piaget, Vygotsky, Bruner and Dewey has become an umbrella term that encompasses many of the more recent learning theories (Pugsley, 2011). Specifically, the social orientations of constructivism commonly linked to Vygotsky which emphasise the critical importance of interaction with people in cognitive development gave rise to social cognitivism (Hung, 2001) while the situated view of learning and practice spawned theories such as situated learning (Lave, 1991) and communities of practice (Lave and Wenger, 1991).

Key concepts in the constructivist view of learning are: learning is an active process of constructing rather than acquiring knowledge; knowledge can be socially constructed involving a discovery of different perspectives and shared meanings or involving a personal discovery of knowledge generally from first principles; and the interpretation of knowledge is dependent on prior knowledge and beliefs held as well as on the cultural and social contexts through which the knowledge was constructed (Hung, 2001). Consequently, reflection, experiential learning and self-directed learning are key elements in this paradigm. Learning is student centred, with the teacher acting as a facilitator of learning, more concerned with constructing a meaningful context for learning rather than directly teaching specific skills (Kerka, 1997). Learning methods based on constructivism include, cognitive apprenticeship, reciprocal teaching, anchored instruction, inquiry learning, discovery learning, problem-based learning and case based-discussions (Yilmaz, 2011, Pugsley, 2011).

Humanism introduced emotions into the learning-performance dynamic with its 'whole person' approach to learning based on the belief that both feelings and knowledge were important to the learning process; by combining the logical and intuition, the intellect and feelings (Smith, 1999). Emotional drives and motivation were considered essential for learning and performance. Humanism is a paradigm, philosophy or pedagogical approach that views learning as a personal act to fulfil one's potential. Rogers and Maslow are credited with originating the humanist movement and they actively brought in the emotional dimension to human learning. The primary purpose of learning was therefore to develop self-actualised, autonomous people (Maslow, 1943; Rogers; 1969).

The Hierarchy of Needs (Maslow, 1943), Facilitation Theory (Rogers, 1969), Experiential Learning Cycle (Kolb, 1984), and Emotional Intelligence (Goleman, 1998) all stem from humanism and its inclusion of the emotional dimension into learning and performance. Learning strategies based on this view include discussion; games for the learning of knowledge; discuss action; project simulation; action plan/contract for the learning of skills and self-assessment and discussion of beliefs for the development of attitudes (Pugsley, 2011). This view which supports the need to move away from traditional education and training delivery approaches towards the personalisation of learning have spawned self-determined learning approaches and personalised learning tools (Lester et al, 2001; Goulding et al, 2014).

Situated learning is learning that takes place in the same context in which it is applied. It was first proposed by Lave and Wenger (1991) where they argued that learning is a social process in which knowledge is co-constructed and such learning is situated in a specific culture and embedded within a particular social and physical environment. They describe the process of such learning as legitimate peripheral participation in a "community of practice". A learner becomes part of the community of practice by beginning at the periphery; then becoming more active and engaged within the culture; and eventually getting to the centre where they assume the role of expert. Social interactions and collaboration are essential components of situated learning (Conole et al, 2004). Apprenticeships are based on situated learning theories.

Modern thinking about learning has however moved away from the dialectic of behaviourism and cognitivism to more holistic, multidimensional and integrated views about learning. Cognitive, constructivist and humanist views integrate within a holist approach that views a person as a whole. Learning is currently viewed as a life-long process involving an individual with both cognitive and emotional dimensions interacting continuously with a social dimension which they affect and are affected by (Kolb, 1984; Illeris 2002, Hager, 2008). The emerging field of the learning sciences is one that is interdisciplinary, draws on multiple theoretical perspectives and research paradigms so as to build understanding of the nature and conditions of learning, cognition and development within context (Barab et al, 2004). Context for learning has moved beyond 'school' to encompass the home and the workplace. In fact it has been argued that most of an individual's learning is done outside of what are usually described as structured learning environments or 'schools' and learning during working life for most individuals spans more than twice the time spent in schooling (Davis and Hase, 2001; Eraut, 2004; Vaughan 2008). Connectivism (Siemens, 2004) and Generativism (Carneiro, 2010) are contemporary learning theories that aim to explain learning in the digital age. The argument is that behaviourism, cognitivism and constructivism do not adequately accommodate the impact of advancements in technology in the learning process.

The underlying principles of connectivism are that learning is a process of connecting specialised nodes or information sources and that capacity to know is more critical than what is known. The reasoning is that knowledge is no longer acquired in a linear manner because chaos, complexity, and the increased interconnections in differing fields of knowledge create an ever shifting reality. Knowledge, information and learning now reside in diverse opinions and also in non-human appliances. It is not now possible for an individual to know and experience everything that they have to deal with so the process of learning involves making the connections between the diverse sources of knowledge, choosing what to learn to solve the current problem by drawing distinctions between important and unimportant information, and being able to detect patterns in the information and to recognise when new information alters the landscape on which the decisions of yesterday were made. The capacity to know more now becomes more critical than what is currently known (Siemens, 2004; Steffens, 2015). Generativism describes learning as an activity which generates new knowledge out of previously codified knowledge involving a constant re-creation of knowledge, deriving new meaning from experience and building sense out of a shared body of conventional knowledge. Learning is collaborative rather than individual (Steffens, 2015). Given these issues, it may no longer be viable for educational systems to input all the knowledge required for life into students during the school years. Lifelong learning and the ability to learn therefore take on greater significance. The skill set for workers in the Knowledge Age (Trilling and Hood, 2001) therefore include: the abilities to locate, assess and represent knowledge; ability to communicate knowledge to others; ability to work productively in collaboration with other people; the abilities to learn, unlearn and relearn; adaptability; creativity; innovative skills; self-awareness; and most importantly, self-directed learning abilities (Toffler, 1970; Kostos, 2006; NZCER, 2014)

In summary, the significant considerations in the effective development of skills are first that learning has no end-point but is a lifelong process, and secondly, the ability to learn involves more than the cognitive but also has social and emotional dimensions (Kolb, 1984; Ellis et al, 1986; Goleman, 1998; Illeris, 2002; Jarvis et al, 2003; Billet, 2004; Blunden, 2006; Illeris, 2007; Hager, 2008; Vaughan, 2008; Bruner, 2009).

The Changing Nature of Knowledge

The changing nature of work, of knowledge and of required skill sets drive the learning process for an industry. This becomes particularly critical in knowledge-based societies with the greater emphasis on knowledge construction and lifelong learning (Kostos, 2006; Vaughan, 2008). Pre-industrial systems of work required practical knowledge and traditional apprenticeships provided an adequate learning system. Industrial Age systems of work, often described as Taylor-Fordist systems, required both propositional and practical knowledge and schools were organised to structure and package knowledge and deliver it to people mostly along the lines of mass production principles (NZCER, 2014).

The transition to the Knowledge Age (Trilling, 2001) has brought about changes in industry marked by movement from Taylorist-Fordist systems of mass production dependent on narrowly defined tasks and strict divisions of labour (Dankbaar, 1999, Cullen, 2002) to knowledge-based systems where organisations are characterised by greater use of technology, flatter hierarchies, elimination of middle management, less supervision, more responsibility and authority at lower levels, employees deployed across functions and departments, multi-skilled workers who are also expected to multitask (Ardichvill, 2003; Brockmann et al 2008). Ardichvill (2003) notes that today's organisations are now expected to be leaner with better motivated workforces that are more productive, innovative, effective and efficient. This suggests that new learning paradigms both at school and beyond school may be required (Kostos, 2006).

Designing Effective Learning Systems for the Construction Environment

An optimal pedagogy is designed with reference to the important related matters of the desired outcome of the learning experience; the intrinsic demands and constraints of the particular domain; the learning methods available; learner variables; and the available resources (Lucas et al, 2012). Understanding the construction environment is integral to understanding the requirements for knowledge and consequently for learning in that environment. The process of designing effective learning within the construction domain therefore begins with defining the outcomes expected of the learning experience. These learning outcomes are prescribed by the specific knowledge and performance requirements of the construction domain and the appropriate theories aimed at delivering effective learning. The expected learning outcomes determine the learning content and to a large extent the learning approaches to be adopted for delivery (Watkins et al, 2002; Lucas et al, 2012). The learning approaches are impinged upon by a social context which further shape and refine them for the development of an appropriate, effective and efficient learning model.

In addition to profession specific skills, a number of generic but key competences have been articulated for life-long learning in the 21st Century and they include: communication; mathematical competence; digital competence; self-regulated learning capabilities; social and civic competence; sense of initiative and entrepreneurship; and cultural awareness and expression (European Council, 2006). These generic competencies encompass not just cognitive but also emotional and social competencies. The cognitive competencies need the support of emotional and the social competences. For instance Steffens (2015) notes that digital technologies have the potential to support learning and expand the availability and flexibility of education but also points out that learning in technology-enhanced environments require the competence to self-regulate one's learning to a much higher degree than the traditional environments. Molnar (2015) discusses practical forms of learning that leverage on digital platforms and presents results of a survey which indicates that motivation, individual learning styles and habits, communication and time management skills impact on the success of teaching and learning in modern digital environments. The low completion rates for most open online courses is attributed to participants' not having the capabilities of effective learners (Steffens, 2015).

Effective learning requires synergy between the three human dimensions of cognition (which deals with the content of knowledge: information, skills, opinions, attitudes, etc.), emotions (which provide the energy, drives, motivation and incentives for learning) and the social dimension (which provides the capabilities for interaction, communication and cooperation with the outside world). The cognitive and emotional dimensions are internal to the individual while the social dimension involves interaction with the external world. Boyatzis and Ratti (2009) identify a set of competencies described as "the underlying characteristics of a person that lead to effective or outstanding performance" and it includes abilities from three clusters: cognitive intelligence competencies, emotional intelligence competencies and social intelligence competencies. These three sets of competencies appear to relate to Illeris (2002) three dimension model for effective learning comprising the cognitive, emotional and social dimension.

Much of formal education has traditionally focused on developing the cognitive abilities without enough attention given to the development of emotional (intrapersonal) and social (interpersonal) competencies. Cognitive ability as a predictor of either academic performance or job performance has been well established in research and in literature. Emotional intelligence theorists however argue that cognitive abilities alone deliver threshold competencies for academic success, getting a job and doing the job, but that analysis of data for outstanding performance and effective human behaviour indicates a requirement for emotional and social intelligence based abilities (Goleman, 2001; Bar-on, 2006). Salovey and Mayer (1990) conclude that emotional skills are necessary for a minimum level of competence and for adequate intelligent functioning.

A review of the literature on construction skills education and training identified two main focal points of discussion: the appropriate proportions of knowledge and skills required (competence v. knowledge debate); and the location of learning (school v. work based learning). The views on either end of these divides dwell on the dialectic of behaviourism and cognitive learning theories which contemporary learning paradigms have moved away from.

Literature on construction skills education and training has focused on the competence v. knowledge debate and the location of learning debate (school v. work place). The views on either end of these divides dwell on the dialectic of behaviourism and cognitive learning theories which contemporary learning paradigms have moved away from to embrace more holistic and integrated views. Holistic learning is characterised by focus on the ‘whole person’, and seeking to engage fully all aspects of the learner: cognitive; emotional; and social. The underlying holistic principle is that an organism functions most effectively when all its component parts are themselves functioning and cooperating effectively (Jarvis and Parker, 2007; Welford, 2015). There appears to be a need to go back to basics and build up from first principles new systems of learning for the construction environment based on holistic learning and appropriate pedagogy that take into consideration the dynamic nature of knowledge, the continuous life-long learning requirements of knowledge economies and technology enhanced learning environments of the digital age.

The questions to be answered therefore are: what are the learning outcomes or attributes or competencies expected of an ideal worker in the construction industry (Cheng et al, 2007; Tabassi, et al, 2011; Lucas et al, 2012)? In recognition of the fact that work has become more complex and rapid change makes it harder to predict occupational futures and very specific skill needs, the capabilities to learn, adapt, change and innovate have become even more critical for construction education. This paper presents the results of empirical studies on the interaction of emotional, social attributes and cognitive ability in relation to job performance in the construction environment.

RESEARCH METHODOLOGY

The research follows a constructivist approach to build understanding of how expertise is developed with specific focus on the influence of the non-cognitive dimensions of learning and performance within the contexts of humanism applied to the construction sector (Bryman, 2008). To provide context a review of extant literature was carried out, covering the overlapping areas between, learning, education, construction industry and performance. Only articles within the overlapping areas were included. The constructs and sub-constructs identified for further investigation were: communication skills; social skills; business-like attitude; motivation; creativity; craftsmanship; numeracy skills; technical skills; underpinning knowledge; performance at work and team working performance.

Communication skills: Communication has been defined variously as any interaction that takes place between people (Donnelly and Neville, 2008); a systemic process in which individuals interact with and through symbols to create and interpret meaning (Wood, 2004); and the imparting or exchanging of information by speaking, writing, or using some other medium (Oxford Dictionaries, 2015). Shepherd et al (2010) summarise the core areas of competency essential for effective interpersonal interactions as self-awareness; effective listening; questioning; oral communication; helping or facilitating; reflecting; assertiveness; and non-verbal communication.

Social skills: Schumaker and Hazel (1984) define a social skill as any cognitive function or overt behaviour in which an individual engages while interacting with another person or persons. Ferris et al (2001) suggest that social skill reflects interpersonal perceptiveness and the capacity to adjust one’s behaviour to different situational demands and to effectively influence and control the responses of others. Individuals high in social skills are able to interpret subtle social cues; to effectively use social perceptions to determine appropriate, timing, sequencing, context and content of an influencing attempt; to improvise when a planned presentation strategy is unlikely to work; and know when to speak and when to keep silent (Ferris, 2001; Schumaker and Hazel, 1984). Seal et al (2015) include abilities such as consideration for others and connection to others while Sackett and Walmsley (2014) found that dependability, cooperation and integrity were rated as important personality attributes for performance in the construction workplace.

Business-like Attitude: An individual worker requires a business objective or sense of purpose to perform optimally whether as a sole trader who is trying to make a living or as part of a multi-national (Lucas et al, 2012). Having a business-like attitude is a positive force that promotes products and services that meet the clients’ or an employer’s needs (Krishnan and Kamalanabhan, 2013). Ultimately business sense would include thinking and acting like an owner of the business, involving exhibiting behaviours such as customer focus; persistence in pushing ideas through to successful implementation; taking the long view required when building something great; taking responsibility for results; and sharing in the vision of the business (Alexander-West, 2013).

Motivation: Human behaviour can be intrinsically motivated, extrinsically motivated and amotivated. Intrinsic motivation is defined as doing something for its own sake because it is interesting and enjoyable. External motivation is doing something for instrumental reasons. On the motivation continuum, intrinsic motivation is at the high end and is driven by emotions that emerge while engaging in the activity while external regulation lies at the low end and refers to doing an activity in order to obtain rewards or to avoid punishment. Amotivation refers to the state of lacking motivation to engage in any activity and is characterised by not being able to make a connection between outcomes and one's actions (Gagné et al, 2010; Vallerand et al, 1992).

Creativity: Creativity has been defined as the development of ideas and products, practices, services and procedures that are novel and potentially useful to organisations (Shalley et al, 2004). A creative person is someone who regularly solves problems, fashions products, or defines new questions in a domain in a way that is initially novel, but ultimately becomes accepted in a cultural setting and a product or response is judged creative if it is novel, appropriate, useful or valuable in solving a problem that is heuristic rather than algorithmic (Amabile, 1996; Gardner and Hatch, 1989; Navaresse et al, 2014). Individuals with innovative cognitive styles are more willing to risk violating the norm in order to develop solutions to problems that are different from previous ones while individuals with adaptive cognitive styles operate within established paradigms and procedures without questioning their validity.

Craftsmanship: Craftsmanship concerns the motivation to do work to a high quality and to produce high quality results. The craftsmanship attribute is different from being a tradesman. Beckham (2002) defines craftsmanship as "pride in work" but Sennet (2008) though agreeing that craftsmanship can reward an individual with pride in work, argues that the rewards are not that simple. It is the desire to do a job well for its own sake and brings job satisfaction that has nothing to do with rewards. Sennet (2008) describes craftsmanship as the skill of making things well, a basic human impulse, the desire to do a job well for its own sake.

Performance at Work: This research was concerned with assessing the results achieved dimension of performance and the behaviours that contribute to organisational effectiveness. The criteria for performance measurement in this research were derived from literature in combination with the perceptions of domain experts on the appropriate criteria for evaluating performance of construction skills obtained during the pilot study (Ene et al, 2015). The list of criteria for assessing job performance is presented in Table 1.

Table 1: Job Performance Criteria (Ene et al, 2015)

Achievement Assessment Criteria	**Contributory Behaviour Assessment Criteria**
• Quantity of work completed (Productivity) • Technical skill • Quality of output • Efficient use of materials • Efficient use of tools and equipment • Efficient use of time • Judgement	• Attitude • Teamwork • Cooperation • Interpersonal relations • Ability to work under pressure • Punctuality • Additional responsibilities (supervision, mentoring, coaching, etc.)

Empirical studies were conducted on the interaction of emotional, social attributes and cognitive ability in relation to job performance in the construction environment. 127 employees of three construction firms in Nigeria participated in this research. Each responded to self-assessment measures that rated specific emotional and social competencies including a general mental ability test as a measure of cognitive competence. The measures for communication skills, social skills, motivation, were developed to cover the subscales identified from literature. Appropriate questions for each subscale were selected from various psychological tests that have been used successfully in other domains (Ferris et al, 2001; Kline, 2000; Messer and Harter, 2012; Queendom, 2015). The measure for performance was developed from a combination of the perceptions of domain experts on the appropriate criteria for evaluation of performance of construction skills obtained from the results from previous work (Ene et al, 2015). This aspect of the research is expected to provide empirical support for directing learning experiences aimed at bridging the personal and interpersonal attributes and performance gaps in learners in school or at work.

RESEARCH FINDINGS

Table 2 outlines each of the measures used in the research. Multiple regression analysis was conducted to examine whether communication skills, social skills, a business-like attitude, motivation, creativity, craftsmanship, numerical skills, technical skills and underpinning knowledge impact on job performance.

Table 2: Summary of research measures

Measure	Sub-scales	Number of Items	Scale
Communication skills	1. Effective listening 2. Questioning 3. Respect for others 4. Verbal communication 5. Reflecting 6. Assertiveness 7. Non-verbal communication 8. Use of work related media	20	4-point Likert scale
Social skills	1. Comfortable with social interaction 2. Empathy and understanding of others 3. Positive engagement with other people 4. Interpreting and adjusting to social cues 5. Choice of socially accepted behaviour 6. Self-control 7. Conflict management	30	4-point Likert scale
Business-like attitude	1. Business objective or purpose 2. Shared vision 3. People orientation and customer focus 4. Ability to create relationships	23	4-point Likert scale

	with contacts 5. Persistence 6. Long view and improvement orientation 7. Responsibility for results 8. Conscientiousness		
Motivation	1. Intrinsic motivation to know 2. Intrinsic motivation to achieve 3. Intrinsic motivation to experience stimulation 4. Extrinsic motivation – identified 5. Extrinsic motivation – introjected 6. Extrinsic motivation – externally regulated 7. Amotivation	28	Global Motivation Scale (GMS-28) (Guay et al, 2003)
Creativity	1. Divergent thinking 2. Lateral thinking 3. Imagination 4. Remote associations	20	4-point Likert scale
Craftsmanship	1. Motivation to do good work 2. Pride in work and in quality of work 3. Desire to perform excellently 4. Willingness to strive for improvement 5. Philosophical understanding of craftsmanship	7	4-point Likert scale
Numeracy skill	1. Mathematics grade (SSCE, GCSE, NABTEB) 2. Simple arithmetic test	1 25	Exam Board grading system
Technical skill	1. Technical skill assessment - 3600 2. (Self + peer1 + peer2 + supervisor)	3	7-point Likert scale
Underpinning knowledge	1. Classroom study of skill	-	Years of relevant schooling
Performance at work	1. Achievement Assessment 2. Contributory behaviour assessment	14	7-point Likert scale
Teamwork	1. Team working ability assessment	3	7-point Likert scale
General Mental Ability (GMA)	1. Verbal and quantitative material	50	Wonderlic GMA test

Multiple regression analysis was conducted to examine the relationships between communication skills, social skills, a business-like attitude, motivation, creativity, craftsmanship, numerical skills, technical skills and underpinning knowledge and job performance. The overall regression model explained 94% (Adjusted R2 = 0.940) of variance which was revealed to be statistically significant, $F = 219.130$, $p < .001$. All the predictors in the model are significant as shown in Table 3.

Table 3: Coefficients of Job Performance

Model		Unstandardised Coefficients		Standardised Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	56.153	2.025		27.735	.000
	Communication skills	.371	.036	.816	10.327	.000
	Social Skills	.126	.030	.284	4.254	.000
	Business-like attitude	.312	.021	.531	14.770	.000
	Creativity	.201	.018	.314	11.100	.000
	Craftsmanship	.335	.020	.938	17.027	.000
	Motivation	.303	.013	.737	22.823	.000
	Numerical skills	.146	.010	.549	13.942	.000
	Technical Skill	.287	.013	.585	22.073	.000
	Underpinning knowledge	.345	.050	.222	6.912	.000

DISCUSSION

The research examined the impact of selected emotional, social and cognitive attributes on job performance and team working abilities. The results indicate that communication skills, motivation and craftsmanship are associated with high levels of performance. These results support emotional intelligence theories which suggest that emotional and social skill contribute (at a minimum) as much as cognitive intelligence to high performance (Goleman, 1998). Figure 1 shows the interactions between cognitive, emotional and social attributes that effect performance.

The determined impact levels have implications for the design and implementation of Higher Education curricula in the built environment as well as for the content and structure of human resource development programmes within organisations. For effective learning to occur, learning experiences have to deliver not just cognitive competencies (knowledge and technical skill) to the individual but also emotional and social competencies which are considered equally important at most job levels and even more important at managerial levels (Goleman, 1998). The focus on development of cognitive skills in isolation limits the potentials for optimal performance of professional and technical staff in the sector. Studies have shown that emotional and social attributes can be learned and they can be developed (Goleman, 1998; Illeris, 2002; Nelis et al, 2011). This paper therefore argues for integration of emotional and social development into learning programmes in schools and in the workplace in the built environment. Focus on the development of the high impact attributes in the individual learners will ensure that the programmes are effective in optimising performance and efficient in terms of time, cost and effort.

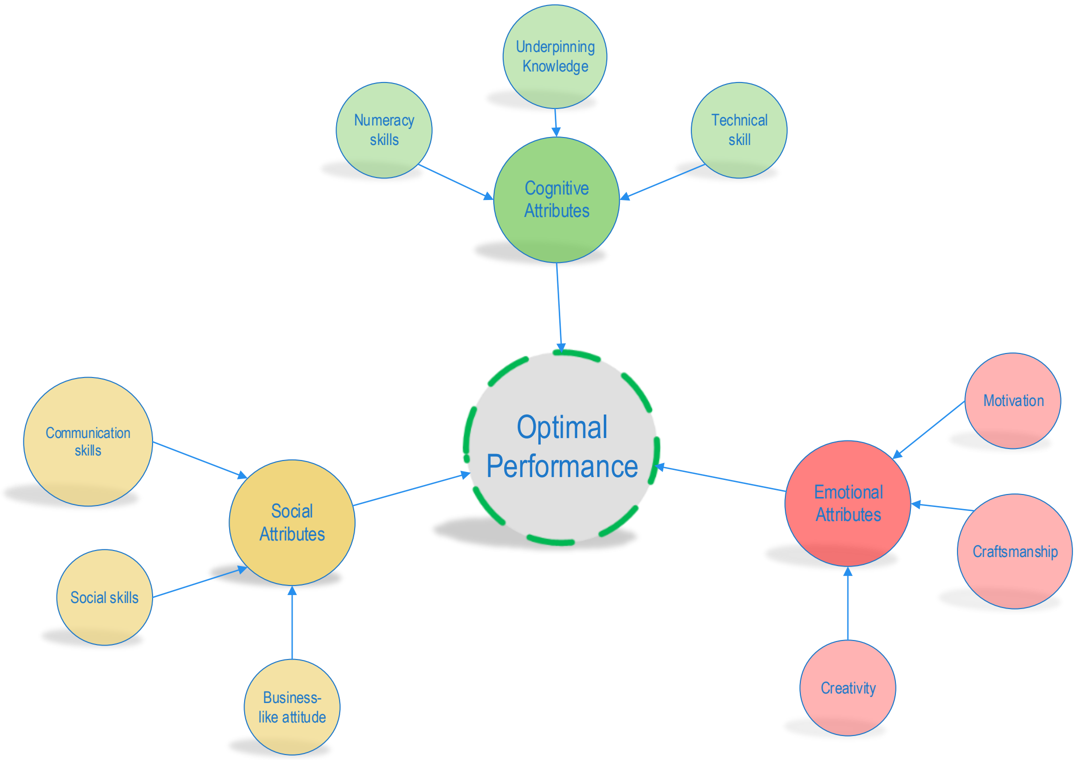
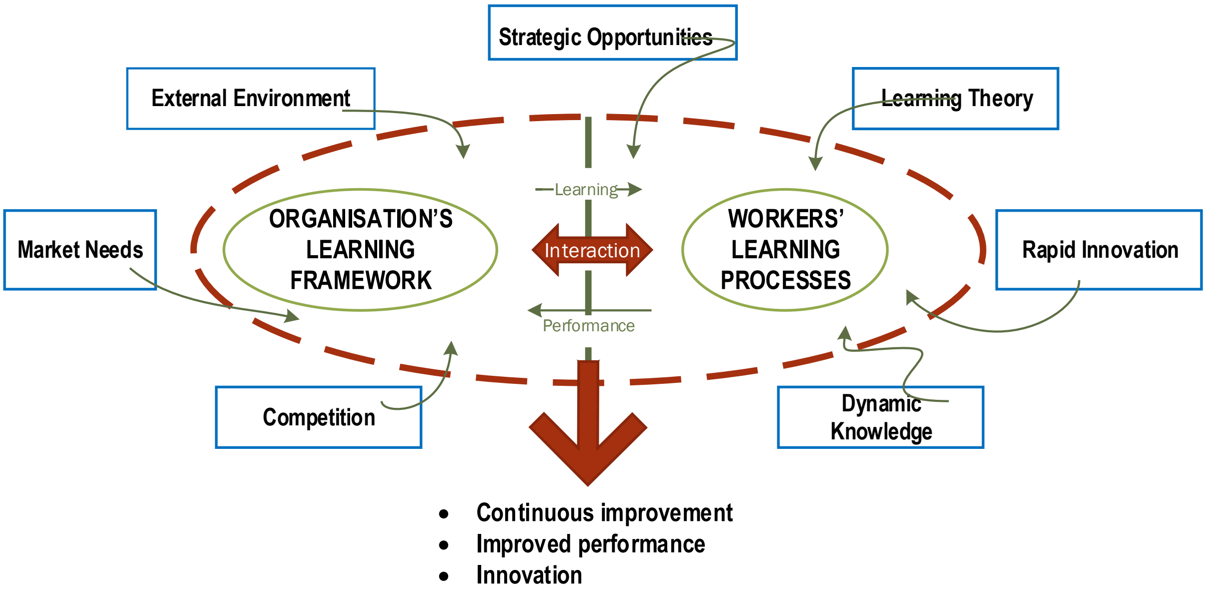


Figure 1: Cognitive – emotional – social dynamic for performance optimisation

From Figure 1, it can be seen that optimal performance is a product of “Cognitive Attributes”, “Social Attributes” and “Emotional Attributes”. However, these need to be placed into the wider context – where learners interact with their workplace and wider environment. These issues are identified in Figure 2. From Figure 2, it can be seen that the core issues for developing a learning and performance optimisation solution for construction needs to appropriate balance a number of core variables, as each are pseudo-symbiotic, in that they underpin and support contextual relevance.

Figure 2: Key elements of a proposed learning and performance optimisation solution for construction (Ene et al, 2015)



CONCLUSION

The changing nature of work and knowledge in the 21st Century calls for changes in the way we organise for learning and education in the construction environment. More holistic approaches to learning are required with focus on the development of the 'whole person'. This in effect will promote the development of effective learners who are capable of and have motivation for self-regulated continuous learning as well as collaborative learning and practice. Learning in the Digital Age has the potential for changing the medium and accessibility to knowledge and education. To harness this potential, individuals require the cognitive (mental), emotional (intrapersonal) and social (interpersonal) competencies which are essential for self-regulated learning. Effective learning capabilities, self-regulated learning capability and digital competence are therefore critical for connecting to, making meaning of and application of the diverse and complex sources of knowledge currently available.

This paper presented the results of an empirical study which highlighted the associations between emotional and social attributes with high levels of performance in the construction environment in Nigeria. This study measured three emotional, three social and three cognitive attributes of workers in construction firms in Nigeria. Multiple regression analyses were conducted to evaluate how well communication skills, social skills, business-like attitudes, motivation, creativity, craftsmanship, numeracy skills, technical skills and underpinning knowledge predicted job performance. The results indicate that communication skills, motivation and craftsmanship are associated with high levels of performance. The paper therefore concludes that since social and emotional attributes can be learned and developed as much consideration should be given to them in the capacity building programmes as is given to cognitive attributes. The measures used to assess social skills, communication skills, business-like attitude, creativity and craftsmanship were developed to fit the purpose of this research by adapting instruments used in other sectors and countries while giving due consideration to the peculiarities of the construction sector in

Nigeria. The participants are employed within three selected construction firms. This research would benefit from a wider spread of participants in order to enhance replicability.

Thus, the premise of this paper is that equipping an individual with knowledge, technical skill, numeracy skill, motivation, creativity, a sense of pride in work, communication skill, social skills, and business awareness and then placing the individual within the framework of any learning environment be it institutional, digital or organisational will provide an individual that will effectively and progressively learn to perform optimally. Further studies will incorporate the findings of this study in a proposed learning model that will enable construction firms to optimise the individual performance of their employees, and consequently optimise the human resource contribution to corporate performance in line with corporate strategy.

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