Emerald Journal of Engineering, Design and Technology

Prevention through design: Conceptual models for the assessment of a Principal Designer's skills, knowledge and experience

Journal:	*Journal of Engineering, Design and Technology*
Manuscript ID	JEDT-07-2020-0278.R2
Manuscript Type:	Original Article
Keywords:	Prevention through design, Skills, Knowledge, Experience, Integrated model, Construction

Prevention through design: Conceptual models for the assessment of a Principal Designer's skills, knowledge and experience

Abstract

Purpose - The prevention through design (PtD) initiative places a duty on designers to originate designs that are inherently safe for construction, maintenance, occupation and demolition. In the UK, legislation has been introduced creating a new statutory role called the Principal Designer (PD) to ensure that PtD occurs during the design process. In order to realize this objective, Principal Designers under the Regulations must have appropriate skills, knowledge and experience (SKE) of occupational safety and health (OSH) risks as they relate to construction products. However, there is a paucity of knowledge, in the extant literature and in practice, regarding what specifically constitutes Principal Designers' skills, knowledge and experience of PtD as well as how to measure same.

Design/Methodology/Approach – The study undertook a systematic review of meanings of skills, knowledge and experience, and carried out content analyses to provide robust conceptualizations of the constructs skill, knowledge and experience. This underpinned the development of nomological networks to operationalize the constructs skills, knowledge and experience in respect of Principal Designers' ability to ensure PtD.

Results – Principal Designers' skills, knowledge and experience of PtD are presented as multi-dimensional constructs that can be operationalized at different levels of specificity in three theoretical models.

Practical implications – The models indicated in this study can assist project clients to clarify the PtD skills, knowledge and experience of prospective Principal Designers in the procurement process. Correspondingly, Principal Designers can look to these frameworks to identify their skills, knowledge and experience gaps and take steps to address them.

Originality/Value – This study contributes to the PtD literature by providing theoretical frameworks to clarify the PtD skills, knowledge and experience of Principal Designers. The study provides a basis for future research to empirically test the attributes of these as they relate to Principal Designers' competence to ensure PtD.

Keywords: Prevention through design; Skills; Knowledge; Experience; Integrated model; Construction

1. Introduction

The construction industry has been the main stay of most economies around the world for many decades (Ruddock and Lopes 2006, Wong et al. 2008, Chiang et al. 2015). It provides several millions of direct and indirect jobs (Ofori 1990, Aires et al. 2016). However, the industry has an unenviable reputation for poor occupational safety and health (OSH) performance relative to other industries (Hughes and Ferrett 2007; Benjaoran and Bhokha 2010). This situation exists in the industry as a result of the varied views and uncoordinated efforts of stakeholders along the project development process in respect of OSH risks management (Krane et al. 2012, Willumsen et al. 2019). In the past, the management of OSH risks on construction projects has been deemed to be the main responsibility of contractors (Rechnitzer 2001, Hare et al. 2006). However, investigations into the root causes of poor OSH performance on construction projects have pointed to the unacceptable procurement and design decisions at the pre-construction stages of the project development process. This revelation now serves as a driver for focusing efforts, in the effective management of OSH risks, on stakeholders (clients and designers) upstream of the project development process in a philosophy termed as "prevention through design (PtD)" (Szymberski 1997, Gibb et al. 2004, Gambatese et al. 2005, Cooke et al. 2008, Lingard et al. 2015). This philosophy places a moral, as well as in some jurisdictions a legal, duty on designers to originate designs or construction products that are inherently safe for construction, occupation, maintenance and demolition. Some researchers (for example, Gambatese et al. 2005, López-Arquillos et al. 2015, Goh and Chua 2016, Poghosyan et al. 2018) have made calls for awareness creation and capacity building among designers to enhance their contributions to effective OSH risk management on projects, particularly at the pre-construction stage.

The nexus between procurement as well as design decisions and OSH risks downstream of the project development process came to the attention of the European Union (EU) and its European Council (EC) responded by adopting Council Directive 1992/57/EEC on the implementation of minimum safety and health requirements at temporary or mobile construction sites. This Directive requires the appointment of two types of coordinators for health and safety matters on construction projects that will require more than one contractor on the construction site. Referred to in this paper as the Pre-Construction Phase Coordinator (PCPC), the first type is to take responsibility for coordination during the design and project preparation stage of projects. The second type of coordinator is referred to as the Construction Phase Coordinator (CPC) who is engaged for coordination of OSH matters during the construction phase of projects. Having national laws providing for the appointment of these two dutyholders on projects is a mandatory requirement of Member States although no details are prescribed for the roles (e.g., the type of professional to exercise it and whether the two roles may be performed by the same entity). In 1994 the UK, then a full member of the EU, transposed the Directive into UK legislation as part of the Construction (Design and Management) Regulations 1994 (CDM 1994). These Regulations imposed statutory safety and health duties on the traditional stakeholders of construction projects – clients, designers, and contractors. They also created the dutyholders of "Planning Supervisor" and "Principal Contractor" with defined statutory duties to take on the performance of the roles of the PCPC and CPC, respectively, under the EC Directive.

The UK's Health and Safety Executive (HSE), the national regulatory authority for health and safety, has had to respond twice to concerns about pre-construction coordination of health and safety matters, attempting to change the role for it each time. About ten years after the CDM 1994 came into force, they were replaced with the Construction (Design and Management) Regulations 2007 (CDM 2007) which changed the label for the pre-construction coordinator from "Planning Supervisor" to "CDM Coordinator". Coordination among relevant stakeholders is at the root of effective OSH risks management on construction projects, particularly at the early stages of the design process (Putsman and McArthur 2015, Bussey 2015). However, under the CDM 2007, evidence from practice indicated that the CDM Coordinators (i.e. PCPCs) were usually not appointed early enough by clients to facilitate the health and safety coordination process (HSE 2014) defeating the PtD ethos espoused by the Regulations. Hence, a review of the CDM 2007 by the HSE considered incorporating the role of the PCPC into the main designer of the construction project as a way of effectively embedding the principle of coordination, in respect of PtD, into the design process (HSE 2014). Additionally, the CDM 2007 required clients to appoint individuals or organizations with individual competence and corporate competence, respectively, in the design and management of construction projects. However, one of the unintended consequences of the regulatory prescription of *competence* and its assessment in an approved code of practice (ACOP) was the proliferation of third party assessment schemes that were uncoordinated, bureaucratic and costly to organizations, particularly the smaller ones (HSE, 2014). CDM 2007 was in turn replaced about eight years later with the Construction (Design and Management) 2015 Regulations (CDM 2015). The key changes made in CDM 2015 were: (a) putting much greater emphasis on the coordination of the pre-construction design process and replacing "CDM Coordinator" with "Principal Designer"; (b) replacement of the requirement for *competences* of dutyholders with *skills, knowledge and experience* of individual dutyholders and *organizational capability* where a dutyholder is an organization.

The Principal Designer, by the Regulations, is appointed by the client at the early stage of the project development process to "plan, manage and monitor the pre-construction phase and coordinate matters relating to health and safety during the pre-construction phase to ensure that, so far as is reasonably practicable, the project is carried out without risks to health or safety" (HSE, 2015). Again, in the replacement of the CDM 2007 with CDM 2015, the HSE has indicated that the health and safety *competence* should be dealt with by way of professional bodies and the industry rather than by a regulatory requirement (HSE 2014). However, there is paucity of knowledge in the extant literature as well as in the construction industry as to what specifically constitutes the skills, knowledge and experience of designers, particularly Principal Designers to ensure that, so far as is reasonably practicable, the design of the construction product is thought out without risks to health or safety. Further, how this competence (skills, knowledge and experience) of the Principal Designer can be specifically assessed is not so clear in the extant literature and in practice. To be able to assess the PtD skills, knowledge and experience of Principal Designers requires an understanding of the attributes of these constructs. In the development of knowledge in a field, the role of theoretical underpinning cannot be over-emphasized (Rule and John 2015; Collins and Stockton 2018). This study, therefore, aims to elucidate or conceptualize through a theoretical lens the skills, knowledge and experience constructs as they relate to Principal Designers' abilities to ensure PtD on projects as a basis for their meaningful operationalization. Second, it provides three integrated models for the measurement and assessment of the PtD skills, knowledge and experience of Principal Designers. These models also provide a basis for taxonomizing the PtD skills, knowledge and experience of Principal Designers. This study particularly focuses on individual Principal Designers. It is expected that further studies consider same for organizational capability as they relate to design firms.

The article is structured in seven sections. The first section provides an introduction and motivation for this study. The second section discusses the prevention through design (PtD) philosophy in construction. The method or approach to the study is provided in the third section. The fourth section focuses on the meanings and theoretical models for measuring and assessing the PtD skills, knowledge and experience constructs. The fifth section provides some discussions on the models with some implications for practice. The sixth section considers the limitations of the study and directions for future studies regarding Principal Designers' PtD competence research. In section seven, the conclusions of the study are offered.

2. Prevention through design (PtD) philosophy in construction

Effective risk management requires proactiveness in efforts and decisions. After-thought decisions and efforts undermine meaningful risk management on any project. Construction risks, particularly OSH risks, until recently have not been managed proactively (Szymberski, 1997; Hare et al., 2006). Consideration of their management, generally, was at points in the project development process (i.e. construction stages) when opportunities to influence them were almost lost or reduced significantly (Szymberski, 1997; Gambatese et al. 2005; Behm, 2005; Hare et al., 2006; Lingard et al., 2015; Manu et al., 2019a). This situation was not helped by the fact that the connection between procurement as well as design decisions upstream of the project development process and OSH risks downstream (i.e. construction, occupation and demolition) of same was not clearly established until recently. This insight has catalyzed stakeholders of the construction product development process, particularly upstream of the chain, to take collective responsibility in minimising OSH risks on construction projects (Gambatese et al. 2005; Behm, 2005; Lingard et al., 2015). This is what has informed the 'Prevention through Design (PtD)' initiative, otherwise considered in literature as 'Design for Safety (DfS)', 'Design for Occupational Safety and Health (DfOSH)', 'Safety in Design (SiD)', 'Construction Hazard Prevention through Design (CHPtD)' and 'Safe Design (SD)'. The ethos of the PtD initiative is to encourage designers to be proactive about OSH risks management, particularly at the early stages of the project development process, to avert harm to project stakeholders downstream of the project chain.

Mostly, when designers make decisions on construction products, their choices determine the materials selection, the dimensions and positions of project features as well as the construction approach which can significantly influence the safety and health of persons involved in constructing, occupying, maintaining and eventually demolishing those construction products (Hinze and Gambatese, 1994; ECI, 1996; Manu et al., 2012; Gambatese and AlOmari, 2016). Hence, some researchers (for example, Cooke et al., 2008; Lingard et al., 2015) indicate that failure to address OSH concerns, early at the design stage of construction products, is at odds with contemporary view of risk management.

Literature indicates that challenges exist regarding the effective implementation of the PtD initiative in practice. For instance, in the USA, Gambatese et al. (2005) indicated the lack of consideration for PtD was mainly due to the designer mindset towards safety as well as lack of knowledge among designers. Additionally, studies (for example, López-Arquillos et al., 2015; Goh and Chua, 2016) have also highlighted the lack of emphasis on PtD in the education of designers in tertiary education institutions.

To augment the PtD initiative, some researchers have developed PtD tools as a way of supporting designers to make contributions in minimising OSH risks on projects. Examples of such tools are design for construction safety toolbox (Gambatese et al., 1997), ToolSHeD (Cooke et al., 2008), injury prevention tool for leadership in energy and environmental design (LEED) (Dewlaney and Hallowell, 2012), construction project features risk management toolkit (Manu, 2012), hierarchy of control (National Institute for Occupational Safety and Health, 2015) and Building Information Modelling (BIM) (Autodesk Incorporated, 2020).

Hardison and Hallowell (2019) indicate that relying on the input or information provided by safety experts as the basis of PtD tools presents three major problems: (1) safety experts may fail to recognize high risk areas in designs due to unfamiliarity of the design itself; (2) a design solution in one environment may not be an optimal design solution in another; (3) a design change that may be optimal in one context may shuffle risk to other locations, phases, exposures, and tasks thereby inadvertently increasing lifecycle risk through sub-optimization. Thus, it appears that, although PtD tools provide opportunity for hazards recognition and realization, they fail to address the effects that PtD suggestions have on the lifecycle safety risks (Hardison and Hallowell, 2019).

Whilst the standard tools and knowledge developed to aid designers in their PtD efforts are commendable, since most projects are unique, some level of PtD skills, knowledge and experience will be expected of Principal Designers and designers to assure project clients of some minimum level of performance. Recent studies (for instance, Goh and Chua, 2016; Poghosyan et al., 2018) have also indicated that clients and end-users provide the greatest motivation for undertaking PtD in the construction industry. Unfortunately, clients are usually indicted for their weak support for PtD on construction projects (Oney-Yazici and Dulaimi, 2014; Hwang et al., 2014). However, are clients of construction projects completely to blame for their inadequate contributions to PtD when, in part, there are no decision support systems to assist them to clarify the PtD skills, knowledge and experience of Principal Designers prior to their engagement? Further, must Principal Designers or designers be solely indicted for their poor contributions to PtD when there are no PtD skills, knowledge and experience frameworks to offer them an opportunity to self-assess and take steps to improve their PtD abilities? In view of this, any efforts to develop frameworks that can assist project clients to clarify the skills, knowledge and experience of Principal Designers and designers prior to engagement as well as offer opportunities for Principal Designers and designers to assess their own performances will be in the right direction.

3. Methods

This study initially conceptualizes the PtD skills, knowledge and experience constructs of the Principal Designer on a construction project, and subsequently develops an integrated model for the operationalization of the constructs. To fulfil the first part, a review of literature on how prior studies have sought to conceptualize skills, knowledge and experience of a worker was undertaken. This was to provide a basis for conceptual content analysis, synthesis and provision of broad conceptualizations of the constructs. Scopus was used as the main database for the literature search with additional information from Google Scholar. In comparison with other databases (e.g. PubMed, Web of Science and Google Scholar), Scopus has an extensive coverage in all fields including science, technology, social sciences, arts and humanities (Chadegani et al. 2013, Mongeon and Paul-Hus 2016). The key search words or phrases were "Concept of skill", "Definition of knowledge", "Concept" AND "Work experience" as well as "Worker Skill, Knowledge and Experience". The search word "Concept of Skill" in Scopus returned 88 results. The search word "Definition of knowledge" in the same database returned 372 results. The "Concept" AND "Work experience" search word returned 936 results while "Worker Skill, Knowledge and Experience" search phrase returned no results. The key search words or phrases were selected to focus the search on studies (such as Aune, 1970; Leplat, 1990; Engestrom, 1994, Quinones et al., 1995; Tesluk and Jacobs, 1998; Sanchez, 2004; Clarke and Winch, 2006; Manu et al., 2019b) that have attempted to define or conceptualize the constructs skills, knowledge and experience as required by the first step of this study approach. The search results in each case covered over 10 subject categories such as construction; engineering; social science; economics and finance; medicine; education; psychology; arts and humanities; computer science; medicine; business, management and accounting, among others. The year ranges, as supplied by Scopus, for the search results were 1976 – 2020, 1964 – 2020 and 1966 – 2020 for the skills, knowledge and experience key search words or phrases, respectively. The searches were done on February 8, 2020.

The identified publications were screened, preliminarily, by checking the abstracts to establish their usefulness to the review. 46, 95 and 150 were passed unto the eligibility stage, respectively for the constructs skill, knowledge and experience. The screened publications were subsequently assessed for eligibility. The main criterion for eligibility was that the publication must clearly indicate a definition for the construct skill or knowledge or experience. 7, 13 and 5 publications were subsequently included in the conceptual analysis and synthesis of the three constructs respectively. As not many publications specifically provided definitions for the constructs in the first search, the reference sections of the publications that provided specific definitions of the constructs were specifically analysed to locate additional relevant publications from Google Scholar in a second search. This second search added 11, 10 and 3 more publications making a total of 18, 23 and 8 publications that were finally considered for the conceptual analysis and synthesis of the constructs skill, knowledge and experience, respectively. Figure 1 indicates the publication selection process adapted from Moher et al. (2009) PRISMA systematic literature review process. This approach was adapted because it uses a systematic and explicit method to identify, select, and critically appraise relevant research, and to collect and analyse data from the studies that are included in the review.

The conceptualizations of the skills, knowledge and experience constructs in the first part of the research approach provided a basis for identifying the common components that explicate each construct, at least from the perspective of previous studies. The common components identified also provided theoretical underpinnings in establishing specific domains or modes of measurement for each construct. Combined with Quinones et al. (1995) and Tesluk and Jacobs (1998)'s postulation of levels of specificity of construct measurement, a nomological network was developed to operationalize these constructs as they relate to the Principal Designer's ability to ensure PtD. They considered the levels of specificity as task, job, work group, organizational and occupational. A nomological network establishes a linkage between the theoretical construct and its observable attributes in an attempt to operationalize the construct (Cronbach and Meehl 1955).

[Figure 1 about here]

4. Meanings and theoretical models for measuring the PtD skills, knowledge and experience constructs of Principal Designers

The Principal Designer's role, like all other roles in every field of engagement, requires some level of competence to effectively fulfill it. One of the key requirements under the CDM 2015 Regulations is that any individual intending to fulfill or be appointed for that role should have skills, knowledge and experience.

4.1 Meaning of skill construct

The concept of skill has always been an elusive one (Barrow 1987, Griffiths 1987, Vallas 1990, Ainley 1993, Evans 1993, Grugulis and Vincent 2009), and has long been contested in the literature (Smith and Teicher 2017). There seems to be diverse theoretical perspectives regarding the construct (Thursfield 2001, Esposto 2008). Sawchuk (2006) indicates that researchers have failed to develop an overarching conceptual framework for skill, partly because the skill literature is highly "siloed" across a range of disciplines including economics, psychology, management, industrial relations, sociology, education and human resource development. That notwithstanding, the understanding of the construct skill has generally been a strong divergence between those, such as psychologists and human capital theorists or economists, who construe skills as being the properties of the job holder rather than the job, and those sociologists who interpret skills from the job requirements' perspective (Vallas 1990, Spenner 1990). Spenner (1990) classify those properties (for example, talents, abilities, capacities and the like) that people bring to the job as individual possessions while those that are required by the job (for instance, task demands, role requirements and positional demands) as social roles.

To better understand the construct skill, a number of definitions are extracted from the extant literature as to how researchers in the past have sought to construe the construct. Such an approach offers an opportunity to do a conceptual or content analysis of prior conceptions of the skill construct to identify some common elements regarding its explication. In this way, a basis is provided to offer a more robust conceptualization of the skill construct to support its objective and systematic measurement. Table 1 indicates the definitions of the skill construct from the extant literature. Critically looking at how various researchers have conceptualized skill, certain commonalities or basic elements of the construct skill become evident. As indicated in Table 1, most researchers (for example, ASME 2010, Sanchez 2004, Leplat 1990, International Labour Office 1990, Attewell 1990, Ainley 1993, Preston 2003, Grugulis 2007, Anderson 2009, Winch 2011, Manu et al. 2019b) construe skill from the perspective of *ability*. Ability here, as indicated in Table 1, refers to attributes independent of the job and are as already possessed by the job holder (see for example, Blunden 1996, Blackmore 1999, IPMA 2015) as well as attributes dependent on and required by the job. Again, another way of conceiving ability is know-how (see for example, ASME 2010, Winch 2011, Clarke and Winch 2006) which will, similarly, be job holder or job dependent.

[Table 1 about here]

Further, a common element in the understanding of the skill construct is *task*. Researchers (for example, Attewell 1990, Leplat 1990, ILO 1990, Ainley 1993, Blunden 1996, Strebler et al. 1997, Preston 2003, Clark and Winch 2006, Grugulis 2007, ASME 2010, Winch 2011, IPMA 2015, Manu et al. 2019b) have conceptualized skills from the perspective of a task. This supports Leplat (1990)'s claim that skill cannot be separated from its object or task in its notion, as to be skilled is basically to be skilled at a task or a class of tasks. Work psychology generally defines a task as "a goal to be achieved in given conditions" (Leplat 1990). In that sense, the value of skills is in its requirement for a goal to be achieved and will most likely be demonstrated or revealed when applied to that goal (Clarke and Winch 2006) under given conditions. In thinking of a task (goal) to be fulfilled, the two fundamental questions that are asked inadvertently simultaneously are: what is required to get this task (goal) done (sociologists perspective) and who is able to get this task (goal) done (psychologists and human capital theorists or economists perspective)? The dichotomy of how skill is conceptualized by these two groups of philosophers is basically reduced to how each group intends to measure skill. This, potentially, can conceal the non-mutual exclusiveness of the "what is required" and "who is able" concerns when thinking of a task (goal) to be fulfilled. Not having an integrated view and looking at the phenomenon in part can underpin a measurement error as far as the construct skill is concerned.

Performance or realisation of desired outcomes is one element that provides understanding of the skill construct. Some researchers (for example, Blackmore 1990, Attewell 1990, ILO 1990, Preston 2003, Grugulis 2007, Manu et al., 2019b) suggest performance in their exposition of the skill construct as indicated in Table 1. The application of ability to a task must, in the end, engender desired outcomes to give true meaning to a skill. Hence, ability (the level of which is determined by the degree of automaticity) should just not be applied to a task but must be combined with awareness (i.e. conscious monitoring of efforts) (Tønnessen 2011) to produce desired outcomes. Elucidating the skill construct from a performance perspective is thus a useful idea.

Holmes and Joyce (1993) indicate three dimensions (job-focused/technical; role-focused/social and person-focused/biographical) in analysing managerial performance. The job-focused/technical dimension considers the specific technical managerial requirements or tasks and what is necessary for carrying out such tasks to deliver performance. On the other hand, the role-focused/social dimension focuses on how managers perceive their environments and negotiate relationships with others to deliver performance. The person-focused/biographical dimension considers managers' dispositions, values, attitudes, behaviours, among others, required in ensuring performance. These dimensions are necessary to understand the skill construct. Abilities are required along all these three dimensions to carry out a task or a group of tasks acceptably. That is to say, one needs to be skilled technically, interpersonally and attitudinally or behaviourally to deliver performance on a task or a group of tasks. Superior performers of tasks do not merely apply required actions, but reflect on their actions (Tønnessen 2011), experiment, and in so doing learn and develop themselves (Kolb and Fry 1984, Dainty et al. 2004). This, therefore, indicates the necessity of attitudes or some underlying characteristics of an individual in demonstrating superior performance at a task (Boyatzis 1982). Over some decades now, studies have used the Big Five personality traits (i.e. openness, conscientiousness, extraversion, agreeableness and neuroticism) in understanding, and as proxies for, non-cognitive skills (Mueller and Plug 2006, Heineck and Anger 2010, Valerio et al. 2016)

Again, some researchers (for example, Ashton and Green 1996, Strebler et al. 1997, ASME 2010) perceive skill as training dependent as indicated in Table 1. This view is based on the fact that the ability to perform a task under given conditions must be predicated on a level of training. In other words, ability necessary for the performance of a task must be developed through training.

None of the prior studies attempts to conceptualize the skill construct by considering all the common components supporting its explication. To provide a broad view in the conceptualization of the skill construct and to underpin its meaningful operationalization, this study therefore defines skill as the ability, both job holder and job dependent, obtained through training, required to perform a task acceptably.

4.2 Measurement of skill

The development of a framework for the measurement of skills is based on Quinones et al. (1995)'s framework which was later extended by Tesluk and Jacobs (1998). Quinones et al. (1995) and Tesluk and Jacobs (1998) adopted a levels approach in the development of a framework for the measurement of worker experience. A levels perspective demands an appropriate definition of constructs and the domain of interest (dimensions of construct) as well as the level of measurement specificity (Klein et al., 1994). A levels perspective, in this case, forces the investigator to think conceptually about the individual, team, organizational and occupational issues as well as possible cross-level effects or domains (Quinones et al. 1995, Tesluk and Jacobs 1998).

This measurement focuses on skills at the individual level and to elicit understanding so that there can be congruence across conceptualization, operationalization and interpretation of the skill construct. Therefore, the first step in the process is to develop a framework that indicates the domain of interest as well as the measures that may be appropriate for each "cell" in the framework.

The framework specifies the main dimensions that describe the various measures of skill as well as the different levels of specificity within each domain (Quinones et al. 1995, Tesluk and Jacobs 1998). This approach juxtaposes the mode of measurement of the skill construct with the specific level where performance is required in order to ascertain the nuances of skill measures or attributes. In that sense, an opportunity is provided to establish a congruence between the measurement mode and the required performance level of the skill construct in a nomological network. The nomological network has two main dimensions as *measurement mode* and *level of specificity*.

Considering the measurement mode dimension, researchers over the past decades have sought to indicate the multidimensional view of the skill construct. For example, sociology researchers (focusing on the nature of skill as a property of the job) have indicated four broad approaches by which skill can be measured (Smith and Teicher 2017). These broad approaches are: positivist/technicist approach; proxy measures approach; social construction approach and soft or generic skills approach. The positivist/technicist approach views skill as a measurable quantity (Felstead et al. 2005) based on indicators such as complexity and autonomy (Adler 2007) in working with things or information. The proxy measures approach views skill in terms of the length of training and wage rate (Spenner 1990, Elias and McKnight 2001, Ruggles et al. 2010, Boucher 2020). Proxy measures are usually criticised as problematic (Grugulis and Lloyd 2010) and mostly used as a result of lack of any other means to measure skill directly (Gatta et al. 2007). On the other hand, the social construction approach attempts to provide belief about skill, as well as their associated hierarchies, through some industrial relations arrangements or institutions. It is considered that the proxy measures of skill as well as the measures used for the positivist/technicist approaches are products of social construction (Steinberg 1990, Smith and Teicher 2017). The soft or generic skills approach, unlike the positivist/technicist, which views skills from working with things and information, considers skills from working with people (Shanmugham and Kishore 2012, Cabral and Dhar 2019). Typical examples being communication and inter-personal skills.

From the conceptual view of the skill construct as well as sociologists' view (Smith and Teicher 2017) of how skill is measured, the specific domains considered for the measurement of skills are: technical/training, autonomy, attitude and interpersonal. The *technical/training* dimension focuses on what specific cognitive abilities (Shanmugham and Kishore 2012), for manipulating things and information, are required for a goal to be achieved. These kinds of abilities can be developed through training.

Technical abilities alone are not enough for individuals to fulfil goals acceptably. Some researchers (for example, Boyatzis 1982, Dainty et al. 2004, Valerio et al. 2016) emphasise the need for certain attitude or behavioral characteristics in fulfilment of goals. An individual may have the technical ability or training but without the requisite attitude or behavourial tendencies, the technical/training ability may not be deployed to best effect with regard to task fulfilment. This is the thrust for the *attitude* measure or domain.

Skill in its infancy or at its lowest level has a low degree of automaticity (Tønnessen 2011) and therefore requires some degree of control or supervision. Thus, an increasing amount of skills is noticed by the level or increasing automaticity in respect of the individual. Further views taken by some researchers (for example, Dreyfus and Dreyfus 1986, Breivik 2016) are that experts (who generally are considered to have high levels of skills) are identified by their immediate and intuitive responses to tasks as opposed to novices who follow instructions and have to be monitored. Skill, thus, can be measured in the domain of *autonomy*.

Tasks are carried out in environments that require interactions and negotiations with other persons (Holmes and Joyce 1993, Smith and Teicher 2017). Interpersonal abilities are, thus, necessary in achieving goals. Hence, *interpersonal* abilities are considered as a mode of measuring the skill construct. Further, considering both the conceptualization and the domains or mode for clarifying skill, the PtD skill required by the Principal Designer to perform optimally, as indicated in Figure 2, can be broadly taxonomized as job-focused/technical skills; person-focused/biographical skill; and role-focused/social skill.

The measures or domains of skill can also vary along the level of specificity (Dubois and McKee 1994, Quinones et al. 1995) at which performance is required. For instance, an individual's level of skill can be linked to specific tasks, jobs, work groups, organizations as well as occupations. The appropriate level of specificity will, very much, depend on the theoretical linkage between skills and the performance or outcome expected. For instance, the technical task requirement is more useful than occupational type when one is interested in task performance. On the other hand, when one is interested in occupational performance, then it will be more relevant to consider the occupational type as opposed to a technical task requirement. As indicated in Figure 2, each of the modes of the skill construct can be operationalized at five levels of specificity (task, job, work group, organizational and occupational) creating a 5 X 4 nomological network for measuring a skill. Illustrations of measures of skills, represented in each cell, are subsequently discussed. Principal Designers can vary in their level of skill with respect to the performance of specific tasks.

First, Principal Designers can vary in their task technical abilities. While some Principal Designers may have deeper cognitive ability about the performance of a task in respect of PtD, some others may not. Second, Principal Designers' level of proficiency, indicating the level of autonomy, at the task level can vary. While some Principal Designers may be very proficient, and thus highly autonomous, in the performance of PtD tasks without support or supervision, other may not. Third, Principal Designers can vary in their attitude towards the performance of a task. For instance, in the performance of tasks in respect of PtD, conscientiousness is required and Principal Designers can vary on this. Fourth, Principal Designers can vary on their task interpersonal abilities. The ease with which Principal Designers can communicate or relate with superiors to obtain information for the performance of their tasks can vary.

At the level of a job, Principal Designers can vary in their job technical abilities. For instance, while some Principal Designers may have a deeper appreciation or technical ability over a wide range or collection of PtD tasks, others may not. Second, the level of autonomy exhibited in the performance of PtD jobs can serve as a distinguishing factor among Principal Designers. For example, while some Principal Designers may require some level of supervision in the performance of their PtD job, others may require absolutely none. Third, the attitude required to carry out a job in respect of PtD can be a distinguishing factor among Principal Designers. Openness to potential risks inherent in construction designs may be a necessary attitude by Principal Designers in the performance of their PtD jobs. Principal Designers can vary on this. Fourth, Principal Designers can vary on their job interpersonal abilities. For example, while some Principal Designers can easily and aptly communicate information in respect of their PtD jobs, others cannot.

Considering the level of work group, Principal Designers can vary in terms of the nature or type of work group they function or may have functioned in. Some Principal Designers may belong to groups that only work on conceptual designs while others may function in detailed design groups. Second, the level of autonomy of groups Principal Designers belong to or have belonged to may distinguish them. For example, some Principal Designers may belong to or might have belonged to design groups that performed autonomously with little or no supervision while others may belong to same with high degree of supervision. Third, the attitude required of Principal Designers at the group level may differentiate them. For instance, at the work group level, an attitude such as agreeableness will be required and Principal Designers can vary along this. Fourth, Principal Designers can vary in their group interpersonal abilities. The Principal Designer role, on projects, requires a significant coordinating ability. Hence, while some Principal Designers have team building spirit and can motivate other team members to deliver optimal performance with regard to PtD, others may not have this attribute.

For the level of organization, Principal Designers may differ in terms of the type of organization in which they have obtained their training or technical abilities over time. Some may be from public organizations where innovation and state-of-the-art knowledge, in respect of PtD, may be limited whereas some may be from private organizations where these are underlying drivers. Second, the position or role a Principal Designer holds in an organization indicates, somewhat, the level of proficiency and hence autonomy he or she possesses in a given craft and Principal Designers can vary on this. Third, Principal Designers can vary on organizational attitude. Construction projects requiring PtD most likely will require the participation of other organizations, particularly at the design stage. An attitude such as extraversion will be necessary to ensure effective performance in respect of PtD and Principal Designers can vary on this. Fourth, Principal Designers can vary on organizational interpersonal ability. Conflict resolution among groups or organizations will be a critical interpersonal ability a Principal Designer must have at the level of organization and Principal Designers can vary on this.

[Figure 2 about here]

At the level of occupation, Principal Designers can vary as to whether they are architects, civil engineers, services engineers and the like. Though all these occupations are considered under the built environment, individuals from any of these professions receive specific technical education and training which may influence their PtD abilities. Principal Designers can vary significantly on this. Second, the establishment of an individual's authority or leadership in an occupation reflects his or her level of expertise and autonomy and Principal Designers can vary on this. Third, Principal Designers can vary on occupational attitude. The current changing socio-economic and technological environments mean that new OSH risks emerge and old ones may no more be relevant. Hence, an occupational attitude of self-efficacy will be required of Principal Designers to keep abreast with current OSH risks in respect of PtD. Fourth, Principal Designers can vary on interpersonal abilities at the occupational level. For example, at the occupational level, excellent communication and persuasive abilities may be required to convince clients and other relevant stakeholders to lend support to the PtD initiative on projects. Principal Designers can vary on this.

4.3 Meaning of knowledge construct

The construct knowledge and skill seem to go together. However, they are both conceptually and practically different (Clarke and Winch 2006). A skill can only be demonstrated through its application to perform or do something while knowledge can be revealed through abstract means of conversation, questioning or working (Clarke and Winch 2006). Therefore, in the context of work, a skill becomes the substrate for eliciting knowledge.

Viewing from a cognitive psychology perspective, different kinds of knowledge can be distinguished, and the distinction between declarative and procedural knowledge is the most widely discussed (Baartman and de Bruijn 2011). Declarative knowledge is the factual information that a person knows and can be reported on (Anderson and Schunn 2000, Hefter et al. 2018). This is often termed as "know what" (Miller 1990, Baartman and de Bruijn 2011, Bernaert and Poels 2011, Śliwa and Kosicka 2017). On the other hand, procedural knowledge is the connection or use of pieces of declarative knowledge and are usually knowledge that cannot be easily communicated (Baartman and de Bruijn 2011) and often considered as "know how" (Miller 1990, Baartman and de Bruijn 2011, Bernaert and Poels 2011, Śliwa and Kosicka 2017). Tacit knowledge (Polanyi 1958, Grant 2007, Ferrari et al. 2016) is a critical part of this knowledge type. A third dimension of knowledge has emerged, referred to as strategic or metacognitive knowledge which pertains to knowledge about the task, context, problem-solving processes as well as oneself (Krathwahl 2002, Barzilai and Zohar 2014, Pathuddin et al. 2018).

To elicit an understanding of the construct knowledge, the same approach as was taken with the skill construct was followed. As indicated in Table 2, the knowledge construct, at least from the perspective of researchers, deconstructs into three main components – information, experience and capability or ability.

Some researchers (for example, James 1907, Plato 1953, Sveiby and Lloyd 1987, Mansfield 1990; Engestrom 1994, Blacker 1995, Myers 1996, Davenport et al. 1998, Nickols 2000, Albino et al. 2001, David and Foray 2003, Kakabadse et al. 2003, Gorelick and Tantawy-Monsou 2005, ASME 2010, Liu 2015, Unger and Hopkins 2016, Manu et al. 2019b) understand knowledge from the perspective of a *collection of information* as indicated in Table 2. However, in the context of work (where performance is desired), information or a collection of it in itself is not useful unless it is situated in context (Aune 1970) and targeted at a particular task (Kakabadse 2003, ASME 2010). For instance, an individual can have information or a collection of it about farming practices. However, in the context of medical practice, that information or a collection of it is not useful and may not constitute knowledge. Context (Aune 1970) justifies the worth of information and adds value to it (Sveiby and Lloyd 1987) in our understanding of knowledge from the perspective of work.

Further, in understanding the knowledge construct, how the knowledge comes about is one element that explicates the construct. Some researchers (for example, James 1907, Blacker 1995, Alle 1997, Davenport et al. 1998, Gorelick and Tantawy-Monsou 2005, Liu 2015, Unger and Hopkins 2016, Manu et al. 2019b), as indicated in Table 2, suggest that *experience* is the bedrock that underlies the acquisition of information about a phenomenon or task which constitutes knowledge. In addition to experience, education or study (for example, Unger and Hopkins 2016, Manu et al. 2019b), is another avenue through which individuals can obtain relevant information, about a phenomenon, which constitutes knowledge. Generally, information obtained about a phenomenon which are recorded and passed on to others through education or study are based on other persons' experiences and views. The underlying conditions and environments that support the validity of the information about a phenomenon may change and thus discredit or invalidate the information. Hence, information through education or study which constitutes knowledge may not be adequate in itself in establishing true knowledge. On the hand, experience as an avenue for information about a phenomenon provides an opportunity for the information to be proven and validated by the individual in certain contexts. This corroborates Plato (1953)'s conceptualization of knowledge as "justified true belief". Experience in this sense engenders a "moment of truth" in respect of information held about a phenomenon which constitutes knowledge.

[Table 2 about here]

There are some researchers (for example, Sveiby 1997, Albino et al. 2001, Gorelick and Tantawy-Monsou 2005, Bennet and Bennet 2008, Liu 2015), as suggested in Table 2, who construe knowledge from the perspective of *capability or ability*. These researchers take the view that the existence of knowledge should make the individual functional or able to carry out a desirable task. This means true knowledge is not about an individual possessing a collection of information about a phenomenon but rather the ability of the individual to leverage the collection of information to perform a task. In that sense, what kind of information an individual, particularly the Principal Designer, must possess in order to be functional establishes a foundation for effective measurement of the individual's knowledge.

An agreement does not exist in literature on the specific conceptualization of the construct knowledge as indicated in Table 2. None of the prior conceptualizations of the construct knowledge considers all the critical elements that explicate the construct. Hence, a more robust conceptualization which encapsulates all the critical elements that explicate the construct knowledge will be necessary. Thus, from the perspective of work and what knowledge is required for, this study proceeds to define knowledge as the collection of information about a phenomenon in a given context obtained through study and experience that enables an individual to perform a task.

4.4 Measurement of knowledge

The same approach after Quinones et al. (1995) and Tesluk and Jacobs (1998) as used in the measurement of the skill construct is employed in the measurement of knowledge. There is a paucity of research on the measurement of the knowledge construct across occupations. Attempts have been made at measuring knowledge in the educational field (Phelps 2004, Hill et al. 2004) but those measurement approaches do so without providing congruence and operationalization of knowledge across different levels of performance requirements. Emphasis of researchers (for example, Phelps 2004, Hill et al 2004) have been on the domains of knowledge measures. For instance, Shulman (1986) in assessing and measuring a subject-matter knowledge for teaching by teachers proposed three dimensions as content knowledge; subject matter knowledge for teaching and curriculum knowledge. The first dimension, content knowledge, according to Shulman includes facts and concepts in the domain as well as why those facts and concepts are true. This dimension of teachers' knowledge corroborated by other researchers (for instance, Ball 1990, Hill et al. 2004) can be considered as *declarative knowledge* (Anderson and Schunn 2000, Baartman and de Bruijn 2011).

The second dimension, subject matter knowledge for teaching, considers what makes a topic under a subject difficult or easy and most importantly how to teach it to the understanding of students. This is an insight beyond the declarative knowledge and focuses on stringing the declarative knowledge to achieve a goal. In essence, this dimension is considered as a *procedural knowledge* (Baartman and de Bruijn 2011).

[Figure 3 about here]

The third dimension, curriculum knowledge, Shulman indicates involves how topics under a subject are both arranged within a school year and over longer periods of time as well as using curriculum resources, such as textbooks, to organise a programme of study for students. Insight into this domain requires a better appreciation of the environment and context and can be considered as a *metacognitive knowledge* (Krathwahl 2002).

The measurement of knowledge of an individual required to carry out a task can therefore be considered in the mode or domains of *content*, *procedural* and *metacognitive* information on the phenomenon. This naturally taxonomizes the knowledge required by an individual to perform a task, particularly the Principal Designer – as indicated in Figure 3 – as content, procedural and metacognitive. Again, relating the domains of knowledge to some levels of performance specificity engenders some congruence and provides, somewhat, comprehensive framework for measuring the knowledge of an individual required to undertake a task, as shown in Figure 3. As indicated in Figure 3, each of the modes of the knowledge construct can be operationalized at five levels of specificity creating a 5 X 3 nomological network for measuring the knowledge of a Principal Designer. Illustrations of measures of knowledge at the levels of task and occupation are discussed, briefly, to provide an overview of the model. Similar discussions hold for the job, work group and organizational levels. Principal Designers can vary on their task content information with regard to what a specific PtD entails. While some Principal Designers may possess more task content information in respect of PtD, others may not. Second, Principal Designers can vary on their task procedural information. Some Principal Designers may possess more tacit information than others regarding how a specific PtD task ought to be performed. Third, metacognitive information about tasks with regard to PtD is another dimension that can distinguish Principal Designers. Some Principal Designers may have more information about when a task required to ensure PtD ought to be performed in the design process as opposed to others.

At the level of occupation, Principal Designers can vary on occupational content information. That will depend on the type of Principal Designer's occupation, whether an architect, civil engineer or services engineer. For example, in a building project design, an architect may have more involvement and possess more OSH risks information about the design as opposed to a services engineer who only focuses on a section of the entire design. Second, Principal Designers can vary on occupational procedural information. For example, some Principal Designers may be more familiar with standards and protocols adopted by some professional bodies in respect of PtD than others. Third, Principal Designers can vary on occupational metacognitive information. Information about which occupations or professions may be required on designs to make effective contributions to PtD may not be possessed or obvious to all Principal Designers and hence distinguish them.

4.5 Meaning of experience construct

The same approach as was with the skill and knowledge constructs was followed in understanding the experience construct. Table 3 indicates the conceptualizations of the experience construct from extant literature. For instance, in explaining the experience construct, some researchers (for example, Fiedler 1970, Pinder and Schroeder 1987, McCall et al. 1988, Quinones et al. 1995, Tesluk and Jacobs 1998, ASME 2010, Manu et al. 2019b), as indicated in Table 3, suggest or emphasize the element of *task*. A task is the object of experience. In the context of work, the requirement for experience becomes relevant when a task has to be performed. Again, a task has to be performed in a particular setting and so some researchers (for example, Marsick and Watkins 1990, Hunt and Wallace 1997) point to the element of *environment* in conceptualising the experience construct. The performance of a task in a given environment provides an opportunity for useful information or knowledge to be obtained. Such information or knowledge, arising from the endeavour in a given environment, either confirm or invalidate prior information or knowledge about a phenomenon, thereby enhancing the understanding of an individual about a phenomenon. In that sense, as indicated in Table 3, some researchers (for example, Fiedler 1970, McCall et al. 1988, Tesluk and Jacobs 1998, Manu et al. 2019b) indicate the element of *information or knowledge* in understanding experience.

The enhancement of the understanding of the individual about a phenomenon with information or knowledge arising from an endeavour occurs over a period of time. Therefore, it is agreed among some researchers (for example, Fiedler 1970, McCall et al. 1988, Quinones et al. 1995, Tesluk and Jacobs 1998) that in explicating the experience construct, there should be the element of *time*.

The usefulness of experience, from the perspective of work, lies in an individual being able to transfer information or knowledge from one context to another. Understanding, through information and knowledge, arising from the performance of a task in a given context is diminished in value, if such understanding cannot be transferred to another context. Again, the ability of an individual to overcome contextual disparities (Pratzner 1985, Blunden 1996) and to demonstrate flexibility in different contexts (Wood 1989) is a critical justification for experience in respect of work performance. Hence, in construing the experience construct, some researchers (for example, Marsick and Watkins 1990, Pinder and Schroeder 1987, Hunt and Wallace 1997) suggest the element of *perceptual or cognitive flexibility*.

There seems to be no specific agreement in the extant literature on the definition or conceptualization of the experience construct. Hence, to provide a broad definition that seeks to reflect all the common elements that clarify experience and to lay a foundation for its measurement, this study – and from the perspective of work – defines experience as the information or knowledge obtained over time by performing a task in a given context, including the ability to overcome contextual disparity.

[Table 3 about here]

4.6 Measurement of experience

The same approach after Quinones et al. (1995) and Tesluk and Jacobs (1998) as used in the measurement of the skill and knowledge constructs is employed in the measurement of experience. Quinones et al. (1995) initially indicated three measures (i.e. amount, time and type) under the measurement mode dimension which were later extended by Tesluk and Jacob (1998) by two additional measures as "timing" and "density".

The *time-based* measure of experience reflects the traditional reliance on tenure on a task, a job or in an organization (Medoff and Abraham 1980, Schmidt et al. 1986, McDaniel et al. 1988). The next measurement mode, *amount*, as a quantitative component measures the number of times a task or duty has been performed (Ford et al. 1991, 1992) as an indicator of individual experience. However, similar to the time-based measure, the amount measure only considers experience in quantitative terms. Little information concerning the nature of those experiences is known and therefore only helps to partially measure the construct experience (Quinones et al. 1995, Tesluk and Jacobs 1998). In clarifying the quality of experience, Quinones et al (1995) indicate the *type* measure. This measure emphasizes the specific work situation that informs the experience by indicating the level of criticality or complexity of the task.

Tesluk and Jacobs (1998) indicate the *density* measure as the intensity of the experience. For example, differences exist in the levels of experience of two individuals who have the same tenure on a task or a job (say one year) but are involved in different number of assignments within the same tenure. Lastly, in extending Quinones et al. (1995)'s measures, Tesluk and Jacobs (1998) indicate the *timing* measure. This measure involves occurrence of work event relative to successive experiences. With the present dynamic work environment, current work experience may appear more useful to very remote experiences. Tesluk and Jacobs (1998) indicate these two additional measures (i.e. density and timing) as interaction components as opposed to the two main categories of measures (i.e. quantitative and qualitative) indicated by Quinones et al. (1995).

Quinones et al. (1995) and Tesluk and Jacobs (1998) indicate a further extension of the nomological network. Hence, in responding to this call, this study attempts to extend the individual work experience measures within the measurement mode dimension. Very little or no attention is paid to the issue of *perceptual or cognitive flexibility* in the measurement of individual work experience. However, the importance of individual work experience in the assessment of future work performance rests on the ability to transfer salient information and knowledge from one or prior work context to another. Thus, perceptual or cognitive flexibility (Pratzner 1985, Wood 1989, Blunden 1996) is one key measure that must be considered in the measurement of experience. This view of how experience is conceptualized as well as the mode or domains for its clarification points to how the experience required by an individual to perform a task, especially the Principal Designer, can be taxonomized. As indicated in Figure 4, the experience of a worker (i.e. Principal Designer) organically taxonomizes into three broad categories as quantitative; qualitative and interaction experiences. The interaction experience mediates the quantitative and qualitative experiences and describes the various types of acquired experiences that depend on a particular dimension of time.

As shown in Figure 4, each of the modes of the experience construct can be operationalized at five levels of specificity creating a 5 X 6 nomological network for measuring the experience of a Principal Designer. Illustrations of measures of experience at the levels of task and occupation, as in the case of the knowledge construct, are discussed briefly to provide an overview of the model. Principal Designers can vary on the number of times they have performed a PtD task. While some Principal Designers may have performed a specific PtD task several times, indicating their levels of experiences, others may not. Second, Principal Designers can vary on the time spent on the performance of a specific PtD task. For instance, some Principal Designers may have relatively longer tenure in the performance of PtD tasks as compared to others.

[Figure 4 about here]

Third, Principal Designers can vary on the type of a PtD task performed in respect of its difficulty, complexity and criticality. While some may be engaged with more difficult, complex and critical tasks, other may not. Fourth, Principal Designers can vary on their PtD task density. Given the same amount of time, some Principal Designers may have performed more PtD tasks, reflecting their level of experience, as compared to others. Fifth, Principal Designers can vary in respect of the recency of the performance of a PtD task. Some may have more recent performance records as opposed to others. Sixth, Principal Designers can vary on their PtD task perceptual or cognitive flexibility. Some Principal Designers can more easily transfer their information and knowledge from one PtD task context to the other in comparison with others.

At the level of occupation, Principal Designers can vary in the number of occupations in which they have been involved. While some may have been involved in several relevant occupations that support their PtD appreciation on projects, others may not. Second, Principal Designers can vary on the amount of time they have spent in an occupation, reflecting their level of experience in that occupation vis-à-vis PtD on projects. Third, Principal Designers can vary on the type of occupation they are engaged in, whether architecture, engineering, or physical science. The level of criticality or complexity of PtD requirements faced by each occupation may differ. Fourth, the dimension of occupational density can distinguish Principal Designers. Given the same amount of time, a Principal Designer may have been engaged in several relevant occupations which may enhance his or her PtD performance in comparison with another. Fifth, Principal Designers can vary on the recency of occupational engagement. While some Principal Designers may demonstrate more recent engagements with occupations relevant for PtD performance on projects, others may not. Sixth, Principal Designers can also vary on occupational perceptual flexibility. The ease with which Principal Designers can transfer relevant information or knowledge obtained in one or prior occupation to another may vary among them.

5. Discussions

The constructs skills, knowledge and experience as they relate to the Principal Designer's competence to ensure PtD are considered as being multi-dimensional in their measurements. Construing these constructs from a single or narrow perspective can potentially undermine their useful measurement. Further, they must be considered as multi-level. Competences of Principal Designers cannot be assumed to exist at all levels (for instance, from a task to an occupational level). The competences that are required at the task level may not be the same as required at the occupational level. Hence, these models have provided effective ways to juxtapose the domains or modes of measurements of the skills, knowledge and experience constructs with the levels where performances are required in other to ascertain the fine-grained or specific skill, knowledge or experience measure under consideration. In this way, the attributes of the constructs as they relate to the Principal Designer to ensure PtD are unpacked from a theoretical perspective. This, thus, contributes to the PtD literature, particularly Principal Designers' or designers' PtD competence research.

Additionally, the Principal Designer's PtD skills, knowledge and experience must be considered as dynamic (Kianto 2008, Teece 2012). Competences, as they reside in Principal Designers, can be considered as assets (Andreu and Ciborra 1996, Mentzas 2004, Adaku et al. 2018). In that regard, it can increase through deliberate and conscious efforts by individuals or deteriorate as a result of lack of individuals' self-efficacy and neglect. Over time, the skills, knowledge and experience of Principal Designers can increase or deteriorate along the *mode of measurement* or the *level of specificity*.

5.1 Practical implications of the models

The proposed models can support project clients to clarify the required skills, knowledge and experience of Principal Designers in the procurement process. Specifically, the attributes of PtD skills, knowledge and experience of Principal Designers as indicated by these models can inform pre-tender interview questions or pre-qualification questionnaires of project clients in the selection of Principal Designers. Correspondingly, the models can similarly serve as a guide for Principal Designers intending to develop their PtD skills, knowledge and experience by providing domains and levels of specificity relevant for such realizations. In other words, Principal Designers can refer to the attributes of PtD skills, knowledge and experience indicated by these models, identify gaps in their PtD competence and take appropriate steps to address such skills, knowledge and experience deficiencies. Some countries have public specifications that assist project clients in assessing and selecting designers, including Principal Designers. For example, in the UK, the publicly available specification (PAS) 91 is one such instrument for construction-related procurement and these models can inform its utilization. The core criteria of Safety Schemes in Procurement (SSIP), a private sector initiative in the UK to assist project clients in the procurement of professional services, can also benefit from these models in a similar way.

6. Limitations and future directions of Principal Designers' PtD competence research

This study has some limitations. Therefore, interpretations placed on the results should be done cautiously. First, the models proposed by this study are not yet validated by the industry. Validation will be required to ascertain which of the attributes of the skills, knowledge and experience constructs, as indicated in the cells, are more relevant and practical in assessing the PtD skills, knowledge and experience of Principal Designers, at least from practice perspective. Second, the models only indicate the attributes of these constructs as they relate to the Principal Designer without specifying which indicators or evidences must be adduced to satisfy those competence attributes. Thus, future studies on Principal Designers' PtD competence should focus on ascertaining the indicators or evidences that must be presented as fulfillment of the attributes.

Further, as the PtD skills, knowledge and experience of Principal Designers are dynamic, an industry framework that seeks to capture these dynamics will be a useful one. Such frameworks could be in the form of competence maturity models and future studies can consider these. Again, future studies can investigate the enablers or constraints of Principal Designers' PtD skills, knowledge and experience development.

These proposed models or nomological networks to measure Principal Designers' PtD competence cannot be deemed complete. Hence, further studies are invited to extend the networks to deepen our understanding and measurement of Principal Designers' PtD skills, knowledge and experience.

7. Conclusions

The prevention through design (PtD) initiative is considered as one of the measures to address occupational safety and health (OSH) risks on construction projects. The skills, knowledge and experience required by Principal Designers to support this initiative are beginning to attract research. The research interest in this areas is perhaps so, because in some parts of the world, such as the UK, Regulations (e.g., CDM 2015) have been developed to place statutory duties on Principal Designers and designers to originate designs that are inherently safe for construction, occupation, maintenance and demolition. However, there are uncertainties as to what constitutes the skills, knowledge and experience of Principal Designers who have an important role under the Regulations to ensure safe designs at the design or pre-construction phase. Further, how to specifically measure or assess the competence (skills, knowledge and experience) of Principal Designers is unclear. Therefore, this study sought to offer understanding of the PtD, knowledge and experience of Principal Designers by proposing three theoretical models that unpack the attributes of these constructs. These models though not yet validated, can offer scope for project clients to think about what skills, knowledge and experience attributes they should expect from prospective Principal Designers regarding their engagements. Similarly, the models can serve as a guide to Principal Designers in respect of their PtD competence development. The models also offer opportunity for the Principal Designer's PtD skills, knowledge and experience to be taxonomized. It is hoped that the theoretical foundation laid by this study will stimulate further investigations regarding the Principal Designer's PtD competence research.

Acknowledgement:

This research has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 837721.

Declarations of interest:

None.

References:

Adaku, E., Amoatey, C. T., Nornyibey, I., Famiyeh, S. and Asante-Darko, D., 2018. Delays in new product introduction: experiences of a food processing company in a developing economy, *Journal of Manufacturing Technology Management*, 29 (5), 811-828.

Adler, P., 2007. The Future of Critical Management Studies: A Paleo-Marxist Critique of Labour Process Theory, *Organization Studies,* 28 (9), 1313–1345.

Ainley, P., 1993. *Class and Skill*, London: Cassell.

Aires, D.M.; Rubio, M.C. and Gibb, A.G.F., 2016. The impact of occupational health and safety regulations on prevention through design in construction projects: Perspectives from Spain and the United Kingdom, *Work: A Journal of Prevention, Assessment and Rehabilitation*, 53, 181-191 DOI 10.3233/WOR-152148

Albino, V., Garavelli, A. C. and Schiuma, G., 2001. A metric for measuring knowledge codification in organization learning, *Technovation*, 21(7), 413-422.

Allee, V., 1997. *The Knowledge Evolution: Expanding Organizational Intelligence*, Boston, MA: Butterworth-Heinemann

American Society of Mechanical Engineers, 2010. *Pipeline Personnel Qualification*, American Society of Mechanical Engineers. ASME B31Q-2010.

Anderson, J. R., and Schunn, C. D., 2000. *Implications of the ACT-R learning theory: No magic bullets*. In R. Glaser (Ed.), Advances in instructional psychology, Vol. 5, educational design and cognitive science. London: Lawrence Erlbaum.

Anderson, P., 2009. Intermediate occupations and the conceptual and empirical limitations of the hour glass economy thesis, *Work, Employment and Society*, 23(1), 169–180.

Andreu, R. and Ciborra, C. U., 1996. Organizational learning and core capabilities development: The role of IT, *Journal of Strategic Information Systems*, 5(2), 111–127.

Ashton, D. and Green, F., 1996. *Education, Training and the Global Economy*, Aldershot: Edward Elgar

Attewell, P., 1990. What is skill?, *Work and Occupations*, 17(4), 422 – 448.

Aune, B., 1970. *Rationalism, Empiricism, and Pragmatism*, New York: Random House.

Autodesk Incorporated, 2020. Designing and building better with BIM. Retrieved from https://www.autodesk.com/solutions/bim – last accessed April 5, 2020.

Baartman, L. K. J. and de Bruijn, E., 2011. Integrating knowledge, skills and attitudes: Conceptualising learning processes towards vocational competence, *Educational Research Review*, 6(2), 125–134

Ball, D. L., 1990. The mathematical understandings that prospective teachers bring to teacher education, *Elementary School Journal*, 90(4), 449–466.

Barrow, R., 1987. Skill talk, *Journal of Philosophy of Education*, 21(2), 187-195.

Barzilai, S. and Zohar, A., 2014. Reconsidering Personal Epistemology as Metacognition: A Multifaceted Approach to the Analysis of Epistemic Thinking, *Educational Psychologist*, 49(1), 13-35.

Behm, M., 2005. Linking construction fatalities to the design for construction safety concept, *Safety Science*, 43(8), 589-611.

Benjaoran, V. and Bhokha, S., 2010. An integrated safety management with construction management using 4D CAD model, *Safety Science*, 48 (3), 395-403.

Bennet, A. and Bennet, D., 2000. Characterizing the Next Generation Knowledge Organization, Knowledge and Innovation: *Journal of the KMCI*, 1(1), 8-42.

Bennet, D. and Bennet, A., 2008. Engaging tacit knowledge in support of organizational learning, *VINE*, 38(1), 72-94.

Bernaert, M., and Poels, G., 2011. The Quest for Know-How, Know-Why, Know-What and Know-Who: Using KAOS for Enterprise Modelling. In: Salinesi C., Pastor O. (eds) Advanced Information Systems Engineering Workshops. CAiSE 2011. Lecture Notes in Business Information Processing, Vol 83. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-22056-2_4

Blacker, F., 1995. Knowledge, knowledge work and organizations: An overview and interpretation, *Organization Studies*, 15(6), 1021-1046.

Blackmore, P., 1999. A categorisation of approaches to occupational analysis, *Journal of Vocational Education and Training*, 51(1), 61-78.

Blunden, R., 1996. The Mind Dependency of Vocational Skills, *Journal of Vocational Education and Training*, 48(2), 167-188, DOI: 10.1080/1363682960480205

Boucher, A. K., 2020. How 'skill' definition affects the diversity of skilled immigration policies, *Journal of Ethnic and Migration Studies*, 46(12), pp. 2533 – 2550. DOI: 10.1080/1369183X.2018.1561063

Boyatzis, R.E., 1982. *The competent manager*, New York: Wiley.

Breivik, G., 2016. The role of skill in sport, Sport, *Ethics and Philosophy*, 10(3), pp. 222-236, DOI: 10.1080/17511321.2016.1217917

Bussey, P., 2015. CDM 2015: *A practical guide for architects and designers*, New Castle upon Tyne: RIBA Publishing.

Cabral, C. and Dhar, R. L., 2019. Skill development research in India: a systematic literature review and future research agenda, *Benchmarking: An International Journal*, 26(7), 2242-2266

Chadegani, A. A., Salehi, H., Yenus, M. M., Farhadi, H., Fooladi, M., Farhadi, M. and Ebrahim, N. A., 2013. A Comparison between Two Main Academic Literature Collections: Web of Science and Scopus Databases, *Asian Social Science*, 9(5), 18-26.

Chiang, Y., Tao, L. and Wong, F. K., 2015. Causal relationship between construction activities, employment and GDP: The case of Hong Kong, *Habitat International*, 46(1), 1-12.

Clarke, L. and Winch, C., 2006. A European skills framework? – but what are skills? Anglo-Saxon versus German concepts, *Journal of Education and Work*, 19(3), 255-269.

Collins, C. S. and Stockton, C. M., 2018. The Central Role of Theory in Qualitative Research, *International Journal of Qualitative Methods*, 17(1), 1–10.

Cooke, T., Lingard, H., Blismas, N. and Stranieri, A., 2008. ToolSHeDTM: the development and evaluation of a decision support tool for health and safety in construction design, *Engineering, Construction and Architectural Management*, 15(4), 336–351.

Council Directive 92/57/EEC, 1992. *On the implementation of minimum safety and health requirements at temporary or mobile constructions sites*, Official Journal No. L 245, 26.08.1992, 6–22.

Cronbach, L. and Meehl, P., 1955. Construct validity in psychological tests, *Psychological Bulletin*, 52(4), 281-302.

Dainty, A. R. J, Cheng, M-I and Moore, D. R., 2004. A competency-based performance model for construction project managers, *Construction Management and Economics*, 22(8), 877-886, DOI: 10.1080/0144619042000202726

Davenport, T. H., De Long, D. W. and Beers, M, C., 1998. Successful knowledge management projects, *Sloan Management Review*, 39(2), 43-57.

David, P.A. and Foray, D., 2003. Economic Fundamentals of the Knowledge Society, *Policy Futures in Education*, 1(1), 20-49.

Dewlaney, K. S. and Hallowell, M., 2012. Prevention through design and construction safety management strategies for high performance sustainable building construction, *Construction Management and Economics*, 30 (2), 165–177.

Dreyfus, H. L. and Dreyfus, S. E., 1986. *Mind over machine: The power of human intuition and expertise in the era of the computer*, New York, NY: Free Press.

Dubois, D. and McKee, A. S., 1994, Facets of work experience. Paper presented at the Ninth *Annual Conference of the Society for Industrial and Organizational Psychology*, Nashville, TN.

Elias, P. and McKnight, A., 2001. Skill Measurement in Official Statistics: Recent Developments in the UK and the Rest of Europe, *Oxford Economic Papers*, 53(3), pp. 508-540.

Engestrom, Y., 1994. *Training for Change: New Approach to Instruction and Learning in Working Life*, Geneva: International Labour Office.

Esposto, A., 2008. Skill: An Elusive and Ambiguous Concept in Labour Market Studies, *Australian Bulletin of Labour*, 34 (1), 100–124.

European Construction Institute (ECI), 1996. *Total Project Management of Construction Safety, Health and Environment*, London: Thomas Telford.

Evans, G., 1993. Windows on education: a skills-referenced perspective, *New Horizons in Education*, 88, pp. 14-27.

Felstead, A., A. Fuller, L. Unwin, D. Ashton, P. Butler, T. Lee, and S. Walters., 2005. *Applying the Survey Method to Learning at Work: A Recent UK Experiment*. Leicester: Centre for Labour Market Studies, University of Leicester.

Ferrari, A., Spoletini, P. and Gnesi, S., 2016. Ambiguity and tacit knowledge in requirements elicitation interviews, *Requirements Engineering*, 21(3), 333–355.

Fiedler, F. E., 1970. Leadership experience and leader performance: Another hypothesis shot to hell, *Organisaional Behaviour and Human Performance*, 5(1), 1-14.

Ford, J. K., Quinones, M, Sego, D. J. and Speer-Sorra J., 1992. Factors affecting the opportunity to perform trained tasks on the job, *Personnel Psychology*, 45(3), 511-527.

Ford, J. K., Sego, D. and Teachout, M. S., 1991. The effects of cognitive ability, job tenure, and the amount of task experience on task proficiency, Paper presented at the *6th Annual Conference of the Society of Industrial and Organizational Psychology*, St. Louis, MO.

Gambatese, J. A., Hinze, J. W. and Haas, C. T., 1997. Tool to Design for Construction Worker Safety, *Journal of Architectural Engineering*, 3(1), 32-41.

Gambatese, J. and AlOmari, K., 2016. Degrees of connectivity: Systems model for upstream risk assessment and mitigation, *Accident Analysis and Prevention*, 93, 251–259. DOI: https://doi.org/10.1016/j.aap.2015.12.020

Gambatese, J., Behm, M. and Hinze, J.W., 2005. Viability of Designing for Construction Worker Safety, *Journal of Construction Engineering and Management*, 131(9), 1029-1036.

Gatta, M., Boushey, H. and Appelbaum, E., 2007. High-touch and Here-to-stay: Future Skills Demands in Low Wage Service Occupations, Paper presented at the workshop organised by the *National Academies Center for Education*, Washington, DC, May 31–June 1.

Gibb, A., Haslam, R., Hide, S. and Gyi, D., 2004. *The role of design in accident causality*, in Hecker, S., Gambatese, J. and Weinstein, M. (Eds), Designing for Safety and Health in Construction: Proc., Research and Practice Symposium, Eugene, OR.: UO Press.

Goh, Y. M. and Chua, S., 2016. Knowledge, attitude and practices for design for safety: A study on civil and structural engineers, *Accident Analysis and Prevention*, 93, 260–266. DOI: https://doi.org/10.1016/j.aap.2015.09.023

Gorelick, C. and Tantawy-Monsou, B., 2005. For Performance through Learning, Knowledge Management Is Critical Practice, *Learning Organization*, 12(2), 125-139.

Grant, K. A., 2007. Tacit knowledge revisited–we can still learn from Polanyi, *The Electronic Journal of Knowledge Management*, 5(2), pp. 173–180.

Griffiths, M., 1987. The teaching of skills and the skills of teaching, *Journal of Philosophy of Education*, 21(2), 203-214.

Grugulis, I., 2007. *Skills, training and human resource development: A critical text*, London, England: Palgrave Macmillan.

Grugulis, I., and Lloyd, C., 2010. *Skill and the Labour Process: The Conditions and Consequences of Change*. In Working Life: Renewing Labour Process Analysis, edited by P. Thompson, and C. Smith, 91–112. Basingstoke: Palgrave Macmillan.

Grugulis, I., and Vincent, S., 2009. Whose Skill is It Anyway? Soft Skills and Polarisation, *Work, Employment and Society,* 23(4), 597–615.

Hall, D. T. and Associates, 1996. *The career is dead-long live the career*, San Francisco: Jossey Bass.

Hardison, D. and Hallowell, M., 2019. Construction hazard prevention through design: Review of perspectives, evidence, and future objective research agenda, *Safety Science*, 120, 517–526. DOI: https://doi.org/10.1016/j.ssci.2019.08.001

Hare, B., Cameron, I. and Duff, A. R., 2006. Exploring the integration of health and safety with pre-construction planning, *Engineering, Construction and Architectural Management*, 13(5), 438-450.

Hefter, M. H., Renkl, A., Riess, W., Schmid, S., Fries, S. and Berthold, K., 2018. Training Interventions to Foster Skill and Will of Argumentative Thinking, *The Journal of Experimental Education*, 86(3), 325-343.

Heineck, G. and Anger, S., 2010. The Returns to Cognitive Abilities and Personality Traits in Germany, *Labour Economics*, 17(3), 535–46.

Hill, H. C., Schilling, S. G. and Ball, D. L., 2004. Developing Measures of Teachers' Mathematics Knowledge for Teaching, *The Elementary School Journal,* 105(1), 11-30.

Hinze, J. and Gambatese, J.A., 1994. Design decisions that impact construction worker safety, Proceedings of the Fifth *Annual Rinker International Conference on Construction Safety and Loss Control*, University of Florida, Gainsville, FL.

Holmes, L. and Joyce, P., 1993. Rescuing the useful concept of managerial competence: From outcomes back to process, *Personnel Review*, 22(6), 37-52.

HSE, 2014. *Consultation on replacement of the Construction (Design and Management) Regulations 2007*, Bootle: HSE.

HSE, 2015. *Managing health and safety in construction: Construction (Design and Management) Regulations 2015. Guidance on Regulations*, London: Health and Safety Executive.

Hughes, P. and Ferrett, E., 2007. *Introduction to Health and Safety in Construction*, Second Edition. Butterworth-Heinemann, Elsevier.

Hunt, J. B. and Wallace, J., 1997. A Competency-based Approach to Assessing Managerial Performance in the Australian Context, *Asia Pacific Journal of Human Resources*, 35(2), 52-66

Hwang, B.G., Zhao, X. and Toh, L.P., 2014. Risk management in small construction projects in Singapore: status, barriers and impact, *International Journal of Project Management*, 32 (1), 116–124.

International Labour Office, 1990. *International Standard Classification of Occupations*, ISCO-88, Geneva: International Labour Office.

International Project Management Association (IPMA), 2015. Individual competence baseline for project, programme and portfolio management, Version 4.0, Nijkerk: IPMA.

James, W. (1907). *Pragmatism*, New York: Longmans.

Kakabadse, N., Kakabadse, A. and Kouzmin, A., 2003. Reviewing the knowledge management literature: towards a taxonomy, *Journal of Knowledge Management,* 7(4), 75-91.

Kianto, A., 2008. Development and validation of a survey instrument for measuring organizational renewal capability, *International Journal of Technology Management*, 42(1), 69-88.

Klein, K. J., Dansereau, F. and Hall, R. J., 1994. Levels issues in theory development, data collection, and analysis, *Academy of Management Review*, 19(2), 195-229.

Kolb, D. and Fry, R., 1984. *Towards an applied theory of experiential learning*. In Cooper, C. (Ed.), Theories of Group Process. New York: John Wiley and Sons.

Krane, H.P., Olsson, N.O.E. and Rolstadås, A., 2012. How project manager-project owner interaction can work within and influence project risk management, *Project Management Journal*, 43(2), 54–67.

Krathwohl, D. R., 2002. A revision of Bloom's taxonomy: An overview, *Theory into Practice*, 41, 212–218.

Leplat, J., 1990. Skills and Tacit Skills: A Psychological Perspective, *Applied Psychology: An International Review*, 39 (2), 143-154.

Lingard, H., Saunders, L., Pirzadeh, P., Blismas, N., Kleiner, B. and Wakefield, R., 2015. The relationship between pre-construction decision-making and the effectiveness of risk control: Testing the time-safety influence curve, *Engineering, Construction and Architectural Management*, 22 (1), 108–124.

Liu, F., 2015. Toward Wisdom: A Hierarchical Wisdom Ontology based on Chinese Classics, *Journal of Information and Knowledge Management*, 14(4), 1-14.

López-Arquillos, A., Rubio-Romero, J. C. and Martinez-Aires, M.D., 2015. Prevention through Design (PtD). The importance of the concept in Engineering and Architecture University courses, *Safety Science*, 73, 8–14. DOI: https://doi.org/10.1016/j.ssci.2014.11.006

Mansfield, B., 1990. *Knowledge, evidence and assessment*, in: H. BLACK H. and A. WOLF (Eds) Knowledge and Competence (London, HMSO).

Manu, P. A, Ankrah, N. A., Proverbs, D. G. and Suresh, S., 2012. Investigating the multi-causal and complex nature of the accident causal influence of construction project features, *Accident Analysis and Prevention*, 48, 126– 133. DOI: https://doi.org/10.1016/j.aap.2011.05.008

Manu, P. A., 2012. *An Investigation into the Accident Causal influence of Construction Project Features*, Unpublished PhD Thesis, School of Technology, University of Wolverhampton, UK.

Manu, P., Gibb, A., Drake, C., Jones, W., Bust, P., Mahamadu, A-M. and Behm, M., 2019b. *Skills-Knowledge-Attitude-Training-Experience (SKATE) in "Designing for Occupational Health of Construction Workers",* Crawley: BandCE Charitable Trust.

Manu, P., Poghosyan, A., Mahamadu, A-M., Mahdjoubi, L., Gibb, A., Behm, M., and Akinade, O., 2019a. Design for Occupational Safety and Health: Key Attributes for Organizational

Capability, *Engineering Construction and Architectural Management*. 26(11), 2614-2636.

Marsick, V.J. and Watkins, K.E., 1990. *Informal and Incidental Learning in the Workplace*, London: Routledge.

McCall, M. W., Lombardo, M. M. and Morrison, A. M., 1988. *The lessons of experience*, New York: Lexington.

McDaniel, M. A., Schmidt, F. L. and Hunter J. E., 1988. Job experience correlates of job performance, *Journal of Applied Psychology*, 73(2), 327-330.

Medoff, J. L. and Abraham, K.G., 1980. Experience, performance, and earnings, *Quarterly Journal of Economics*, 90, 703-716.

Mentzas, G., 2004. A strategic management framework for leveraging knowledge assets, *International Journal of Innovation and Learning*, 1(2), 115-42.

Miller, G. E., 1990. The assessment of clinical skills/competence/performance. *Academic Medicine*, 65(9), 63–67.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D., 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement, *Annals of Internal Medicine*, 151(4), 264–269.

Mongeon, P., Paul-Hus, A., 2016. The journal coverage of Web of Science and Scopus: a comparative analysis, *Scientometrics,* 106(1), 213–228.

Mueller, G. and Plug, E., 2006. Estimating the Effect of Personality on Male and Female Earnings, *Industrial and Labor Relations Review*, 60(1), 3-22.

Myers, P. S., 1996. *Knowledge Management and Organizational Design*, Boston, MA: Oxford, Butterworth-Heinemann.

National Institute for Occupational Safety and Health (NIOSH), 2015. Hierarchy of controls. Retrieved from www.cdc.gov/niosh/topics/hierarchy - last accessed November 28, 2019.

Nickols, F., 2000. *The Knowledge in knowledge (KM), Knowledge Management Yearbook*, London: Heinemann.

Nonaka, I., Toyama, R., and Nagata, A. 2000. A firm as a knowledge-creating entity: A new perspective on the theory of the firm, *Industrial and Corporate Change*, 9(1), 1-20.

Ofori, G., 1990. *The construction industry: Aspects of its economics and management*, Singapore: Singapore University Press.

Oney-Yazıcı E. and Dulaimi M. F., 2014. Understanding designing for construction safety: the interaction between confidence and attitude of designers and safety culture, *Architectural Engineering and Design Management*, 11(5), 325-337.

Pathuddin, Budayasa, I. K. and Lukito, A., 2018. Metacognitive Knowledge of a Student in Planning the Solution of Limit Problems, *Journal of Physics: Conference Series*, 1108(1), 1-6. DOI:10.1088/1742-6596/1108/1/012032

Phelps, G. and Schilling, S., 2004. Developing Measures of Content Knowledge for Teaching Reading, *The Elementary School Journal*, 105(1), 31-48.

Pinder, C. C and Schroeder, K. G., 1987. Time to proficiency following job transfers, *Academy of Management Journal,* 30(2), 336-356.

Plato, 1953. *Phaedo*, Plato l, trans. By Gower, H. N., Harvard University Press/The Loeb Classical Library, Cambridge, MA, 117-24.

Poghosyan , A., Manu, P., Mahdjoubi, L., Gibb, A. G. F., Behm, M., and Mahamadu, A. M., 2018. Design for safety implementation factors: a literature review. *Journal of Engineering, Design and Technology*, 16(5), 783-797.

Polanyi, M., 1958. *Personal Knowledge: Towards a Post-Critical Philosophy*, Chicago: University of Chicago Press.

Pratzner, F.C., 1985. The vocational education paradigm: adjustment, replacement, or extinction?, *Journal of Industrial Teacher Education*, 22(2), 6-19.

Preston, J. E., 2003. *Studies in Management Module* No. ILM5220, 2nd edn. Aberystwyth: Open learning Unit, University of Wales Aberystwyth.

Putsman, T. and McArthur, P., 2015. *Practical guide to using CDM Regulations 2015: teamwork and paperwork*, London: ICE Publishing.

Quinones, M. A., Ford, J. K. and Teachout, M. S., 1995. The relationship between work experience and job performance: A conceptual and meta-analytic review, *Personnel Psychology*; 48(4), 887-910.

Rechnitzer, G., 2001. *The Role of Design in Occupational Health and Safety: A Discussion Paper*, Melbourne: Safety Institute of Australia.

Reynolds, M. and Salters, M., 1995. Models of Competence and Teacher Training, *Cambridge Journal of Education*, 25(3), 349-359, DOI: 10.1080/0305764950250306

Ruddock, L. and Lopes, J., 2006. The construction sector and economic development: The Bon Curve, *Construction Management and Economics*, 24 (7), 717-723.

Ruggles, S., Trent A., Genadek, K., Goeken, R., Schroeder, M. and Matthew Sobek, M., 2010. *Integrated Public Use Microdata Series: Version 5.0*. Minneapolis: University of Minnesota.

Rule, P., and John, V. M., 2015. A necessary dialogue: Theory in case study research. *International Journal of Qualitative Methods*, 14, 1–11. DOI: https://doi.org/10.1177/1609406915611575

Sanchez, R., 2004. Understanding competence-based management Identifying and managing five modes of competence, *Journal of Business Research*, 57(5), 518– 532.

Sawchuk, P. H., 2006. Use-value' and the Re-thinking of Skills, Learning and the Labour Process, Journal *of Industrial Relations*, 48 (5), 593–617.

Schmidt, F. L., Hunter, J. E. and Outerbridge, A. N., 1986. Impact of job experience and ability on job knowledge, work sample performance, and supervisory ratings of job performance, *Journal of Applied Psychology*, 71(3), 432-439.

Shanmugham, M. and Kishore, S., 2012. Integration of prior learning and assessment in the IGNOU community college system for Skill Development, *Turkish Online Journal of Distance Education,* 13(2), 311-321.

Shulman, L. S., 1986. Those who understand: Knowledge growth in teaching, *Educational Researcher*, 15(2), 4–14.

Śliwa, M., and Kosicka, E., 2017. A model of knowledge acquisition in the maintenance department of a production company, *Applied Computer Science*, 13(3), 41–54.

Smith, E. and Teicher, J., 2017. Re-thinking skill through a new lens: evidence from three Australian service industries, *Journal of Education and Work*, 30(5), 515-530.

Spenner, K., 1990. Skill: Meanings, Methods, and Measures, *Work and Occupations,* 17 (4), 399–421.

Steinberg, R., 1990. Social Construction of Skill: Gender, Power, and Comparable Worth, *Work and Occupations,* 17 (4), 449–482.

Strebler, M., Thompson, M. and Heron, P., 1997. *Skills, Competencies and Gender: Issues for pay and training*, Brighton: Institute for Employment Studies.

Sveiby, K. E., 1997. *The New Organizational Wealth: Managing and Measuring Knowledge-based Assets*, San Francisco, CA: Berret-Koehler.

Sveiby, K., and Lloyd, T., 1987. *Managing knowhow: Add value by valuing creativity*. London: Bloomsbury.

Szymberski, R.T., 1997. Construction Project Safety Planning, *Tappi Journal*, 80(11), 69-74.

Teece, D. J., 2012. Dynamic capabilities: Routines versus entrepreneurial action, *Journal of Management Studies*, 49(8), 1395–1401.

Tesluk, P. E. and Jacobs, R. R., 1998. Toward an Integrated Model of Work Experience, *Personnel Psychology*, 51(2), 321-355.

Thursfield, D., 2001. Employees' perceptions of skill and some implications for training in three UK manufacturing firms, *Human Resources Development International*, 4(4), 503–519.

Tønnessen, F. E., 2011. What are skills? Some fundamental reflections. L1-Educational Studies in Language and Literature, 11(1), 149-158. http://dx.doi.org/10.17239/L1ESLL-2011.01.09

Unger, M. and Hopkins, P., 2016. Training and Education: The Great Competence Divide…, Proceedings of the 11th *International Pipeline Conference*. IPC2016 September 26-30, 2016; Calgary, Alberta, Canada. IPC2016-64500

Valerio, A., Puerta, M. L. S., Tognatta, N. and Monroy-Taborda, S., 2016. *Are There Skills Payoffs in Low- and Middle-Income Countries? Empirical Evidence Using STEP Data*, Policy Research Working Paper 7879, The World Bank Group.

Vallas, S., 1990. The concept of skill: A critical review, *Work and Occupations*, 17(4), 379-398.

Willumsen, P., Oehmen, J., Stingl, V. and Geraldi, J., 2019. Value creation through project risk management, *International Journal of Project Management,* 37(5), 731– 749.

Winch, C., 2011. Skill: a concept manufactured in England. In: Brockmann, M., Clarke, L., Winch, C., Hanf, G., Méhaut, P., Westerhuis, A. (Eds.), *Knowledge, Skills and Competence in the European Labour Market: What's in a Vocational Qualification?* Routledge, Abingdon, 85–101.

Wong, J. M. W, Chiang, Y. H. and Ng, T.S., 2008. Construction and economic development: The case of Hong Kong, *Construction Management and Economics*, 26 (8), 813-824

Wood, S., ed., 1989. *The Transformation of Work? Skill, flexibility and the labour process*. London: Unwin Hyman.

Table 1: Literature definitions of skill

Definition	Source
The ability to perform mental and physical activities acquired or developed through training or experience	American Society of Mechanical Engineers (ASME) (2010)
The level of training a job requires	Strebler et al. (1997)
Special forms of capability, usually embedded in individuals or teams, that are useful in specialized situations or related to the use of a specialized asset	Sanchez (2004)
The human capacities that are required for successful performance.	Blackmore (1999)
The capacity (or ability) of an individual to execute a task or a class of tasks	Leplat (1990)
The ability to do something well.	Attewell (1990)
A specific ability of an individual, typically manual and/or coordinative features, which is geared to a task – or, more precisely, a task type – itself quite a narrow category, involving the application of a technique.	Winch (2011)
The ability to carry out the tasks and duties of a job in a competent, thorough and efficient manner	Anderson (2009)
Application of mental and manual abilities to a task or occupation	Ainley (1993)
The ability to perform a task or exercise that will result in a desired outcome	Preston (2003)
Skills are conceived in terms of social attributes, general education, training, qualifications, and technical skills	Ashton and Green (1996)
A possession of know-how appropriate to the task in hand and not necessarily a possession of a 'qualification' or certification	Clarke and Winch (2006)
The ability to carry out the and duties of a job in a competent manner	International Labour Office (ILO) (1990)
A relation between certain aspects of the worker and certain aspects of the job which he or she undertakes	Blunden (1996)

Combinations of automaticity and awareness (i.e. conscious monitoring and possible correction in the performance of the task) in a situationally appropriate manner.	Tønnessen (2011)
The ability to do something well, expertise, practice, capability, aptitude, etc	Manu et al. (2019b)
Specific individual capabilities that enables an individual to perform a task	International Project Management Association (IPMA) (2015)
Doing something well	Grugulis (2007)

Table 2: Literature definitions of knowledge

Definition	Source
Collection of information and experience an individual possesses	International Project Management Association (IPMA) (2015)
A body of information applied directly to the performance of a task	American Society of Mechanical Engineers (ASME) (2010)
Understanding gained through experience or study	Unger and Hopkins (2016)
A collection of immovable, ready-made facts	Engestrom (1994)
Facts, information or data	Mansfield (1990)
Information, facts or familiarity gained by experience or education; the practical or theoretical understanding of a subject etc	Manu et al. (2019b)
Consists of cognitive states needed to interpret and otherwise process information	David and Foray (2003)
Justified true belief	Plato (1953); Nonaka et al. (2000)
Information put to productive use	Kakabadse, et al. (2003)
Meaningful and organised accumulation of information through experience, communication or inference	Blacker (1995)
Value added information	Sveiby and Lloyd (1987)
Information in context	Aune (1970)
Understanding based on experience	James (1907)
Experience or information that can be communicated or shared	Allee (1997)
Data and information that inform an understanding of a situation, relationships, causal phenomena, and the theories and rules (both explicit and implicit) that underlie a given domain or problem	Bennet and Bennet (2000)
A capacity to act	Sveiby (1997)
Knowing about something, knowing how to do something, or accumulated facts or records	Nickols (2000)
Processed information	Myers (1996)
Information combined with experience, context, interpretation and reflection, a high-value form of information.	Davenport et al. (1998)
The capacity (potential or actual) to take effective action in varied and uncertain situations	Bennet and Bennet (2008)
The know-how, experience, insight, and capabilities that assist teams and individuals in making correct and rapid decisions, taking action and creating new capabilities	Gorelick and Tantawy-Monsou (2005)

The information possessed by an entity that enables the entity to carry out a task.	Albino et al. (2001)
Memory of experience of decision making by consciousness, from cognition, rational thinking to hypothesis and belief, that leads to a solution to a problem	Liu (2015)

Table 3: Literature definitions of experience

Definition	Source
Work activities accomplished under the direction of qualified supervision but not including time spent in organised training programs	American Society of Mechanical Engineers (ASME) (2010)
Involvement/participation in a given subject; actual observation or practical acquaintance with facts or events, with knowledge and/or skills resulting from this	Manu et al. (2019b)
A valuable understanding of a particular working environment or organizational context	Hunt and Wallace (1997)
Ways in which people make sense of situations they encounter in their daily lives and especially in workplace settings	Marsick and Watkins (1990)
The amount of time spent on or number of times a task has been performed	Quinones et al. (1995)
Job-relevant knowledge gained over time	Fiedler (1970); McCall et al. (1988)
The degree of similarity between a person's previous job and current job	Pinder and Schroeder (1987)
Job-related knowledge, skills and attitude an individual has accumulated over the course of his/her career	Tesluk and Jacobs (1998)

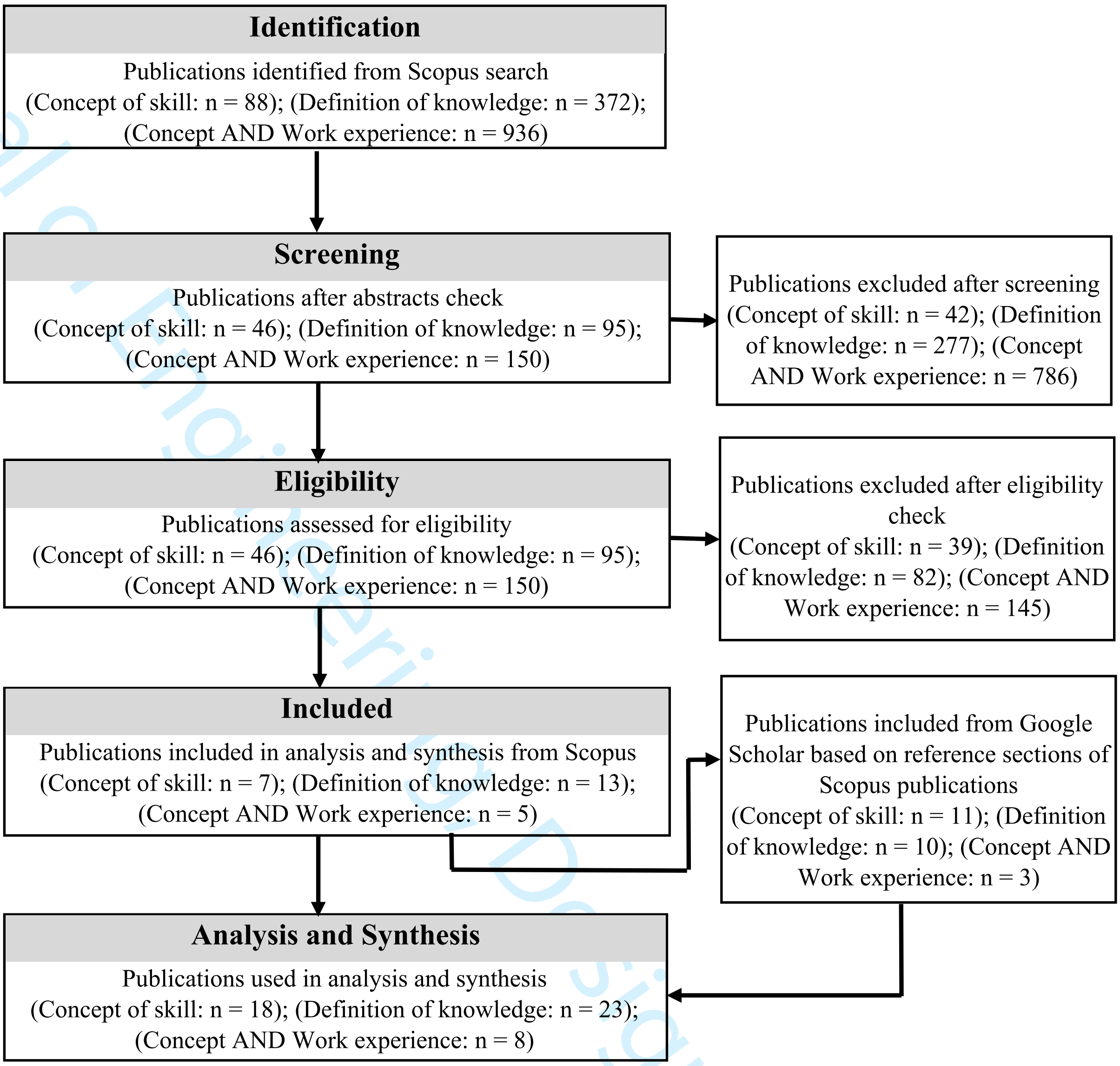

Figure 1: Publication selection process adapted from Moher et al. (2009)

Level of Specificity	Job-focused/Technical Skill		Person-focused/Biographical Skill	Role-focused/Social Skill
Occupational	Occupational type (e.g. Architect, Civil Engineer, etc)	Occupational leadership	Occupational attitude	Occupational interpersonal ability
Organizational	Organizational type (e.g. Public, private, etc)	Organizational position/role	Organizational attitude	Organizational interpersonal ability
Work Group	Nature or type of work group	Group autonomy	Group attitude	Group interpersonal ability
Job	Job technical ability	Job autonomy	Job attitude	Job interpersonal ability
Task	Task technical ability	Task autonomy	Task attitude	Task interpersonal ability
Measurement Mode	Technical/ Training	Autonomy	Attitude	Interpersonal

Figure 2: A conceptual framework of skill measures

Level of Specificity	Content Knowledge	Procedural Knowledge	Metacognitive Knowledge
Occupational	Occupational content information (e.g. Architecture, Engineering, etc)	Occupational procedural information	Occupational metacognitive information
Organizational	Organizational content information	Organizational procedural information	Organizational metacognitive information
Work Group	Work group content information	Work group procedural information	Work group metacognitive information
Job	Job content information	Job procedural information	Job metacognitive information
Task	Task content information	Task procedural information	Task metacognitive information
Measurement Mode	Content	Procedural	Metacognitive

Figure 3: A conceptual framework of knowledge measures

Level of Specificity	Quantitative Experience		Qualitative Experience	Interaction Experience		
Occupational	Number of occupations	Occupational tenure/seniority	Type of occupation (e.g. Engineering, Architecture, etc)	Occupational density	Recency of occupational engagement	Occupational perceptual flexibility
Organizational	Number of organizations	Organizational tenure/seniority	Type of organization (e.g. R&D, Public, etc)	Organizational density	Recency of Organizational engagement	Organizational perceptual flexibility
Work Group	Number of work group	Group tenure/seniority	Group complexity	Group density	Recency of group engagement	Group perceptual flexibility
Job	Number of jobs or aggregation of tasks	Job tenure/seniority	Job complexity	Job density	Recency of job	Job perceptual flexibility
Task	Number of times of performing a task	Time on task	Task difficulty	Task density	Number of times of performing a task	Time on task
	Amount	Time	Type	Density	Timing	Perceptual/ Cognitive Flexibility

Measurement Mode

Figure 4: A conceptual framework of experience measures

Response to Reviewers

Reviewer #1:

We thank the reviewer for the insightful comments provided. We believe we have captured and addressed fully all the minor comments, concerns and suggestions. We use the table below to show the comments of the reviewer and our response to those comments. All our revisions are indicated in RED colour fonts in the main manuscript.

Comment	Response
1. Proof-read the manuscript to correct language errors	We are happy to indicate that the manuscript is now proof-read and all language errors corrected.
2. Consider reviewing the arrows and directions between stages “Included” and “Analysis and synthesis” in Figure 1.	We thank the Reviewer for this comment. Respectfully, we are of the view that a change in the arrows and directions will alter our considered and described approach to the systematic review under the method section. We did a second search, in Google Scholar, after analyzing the reference sections of the “included” studies from Scopus.