Concept proofing a proposed early-stage project complexity assessment tool

Paulo Vaz-Serra[1,] Peter Edwards[1&2] and Guillermo Aranda-Mena[2]
[1]*The University of Melbourne, Melbourne, Australia*
p.vazserra@unimelb.edu.au
[2]*RMIT University, Melbourne, Australia*
peter.edwards@rmit.edu.au, *guillermo.aranda-mena@rmit.edu.au*

Abstract: Project complexity, as a sub-field of complexity science, is under-researched in terms of what factors contribute to it; how they can be assessed; and what can be done to deal with them. This research proof-tests the concept of a project early stage complexity assessment tool (PESCAT), based upon complexity theory, that uses project differentiation, inter-dependency and uncertainty as measures for subjective assessment. Using focus group workshops comprising a convenience sample of construction professionals, mixed methods research (including opinion survey questionnaire, hypothetical and real-life case studies) is used within a qualitative framework to explore aspects of project complexity and the application of the proposed assessment tool. The findings confirm that an early stage project complexity assessment tool is practicable and can contribute to project management practice in the construction industry. Such a tool should be applied in a small group setting by individual project stakeholders and customised according to their needs and the nature of their involvement. Tool development suggests that four measures (differentiation and its associated uncertainty, and interdependency and its uncertainty) are appropriate measures, provided that they are applied to project perspective factor sets that reflect the construction project management processes of different stakeholders.

Keywords: Project complexity, assessment, project management, construction industry

Introduction

While complexity science is a large field of investigation, its application to construction projects is quite sparse, given the size of the architecture, engineering and construction (AEC) industry, the nature of the projects undertaken, and the abundance of academic journals and commercial magazines in the field. Although some project factors may be regarded as complicated, little thought is given as to why and how the project itself should be considered complex. From a systems viewpoint, construction projects probably lie in the dynamic imposed category (situations may change within a predetermined approach). Solutions do not always take in consideration relationships between the built environment and its nature of "entangled complexity" (Sharp, 2012). Ali *et al.* (2020) note that delivering a construction project involves a sequence of tasks and that are performed in series and/or parallel and organising the tasks in itself creates a complex system. For example, alteration and refurbishment projects are categorized as

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very complex in nature (Chong et al., 2017; Okakpu et al., 2020) as task organisation in such projects is associated with high levels of uncertainty.

Other than relying on previous experience, stakeholders in a project do not necessarily know in advance exactly where any complexities will lie nor their full extent. However, if it can be assessed at an early stage of project development, when little detailed information may be available, a better understanding of the nature and extent of project complexity could valuably inform project decision-making and the use of management resources. Cooke (2013) hypothesises that, for reducing uncertainty, using a singular common model in the early project design stage could be a practical solution to ensure integration of structural and engineering components.

This paper covers the design and concept-proofing of an early stage project complexity assessment tool.

Our research focuses on construction projects. Construction, as a project-driven industry, is prone to high resource demands and uncertainty that influence construction costs. Successful application of the proposed early stage project complexity assessment tool could therefore potentially yield strategic and national benefits through its contribution towards a more efficient AEC industry. This aligns with the view of Elia *et al.* (2020) who propose an integrated framework, a system thinking based approach, called "project management canvas" to support a contextual management of project complexity.

We commence with a brief theoretical background established through literature review. This is followed by the conceptual complexity assessment tool design; proposed research methodology; focus group workshop processes (including survey questionnaire administration and tool application testing); and data analysis flowing from these. The preliminary results are discussed; subsequent tool modifications are proposed, and conclusions are drawn.

The aim and innovative contribution of this research project is to use focus group workshops as a means of testing and validating the project complexity assessment tool concept. The proximity of industry practitioners, and the interactions between them during and following a sequence of workshop exercises should be enough to proof-test the concept, at least for a construction industry environment.

Theoretical background

In this section complexity is explored from theoretical, system and project standpoints. These are drawn together in the context of project decision-making and uncertainty.

Complexity

A general dictionary definition of *complexity* describes it as a state of being complex, which in turn is explained as consisting of several closely-connected parts, complicated, intricate, hard to understand.

Complex systems

Remington and Pollock (2007) typify complexity in systems as *structural* (variability in the "what"); *technological* (the "how"); *temporal* ("when" effects); and *directional* (change going from "where to where"); thus adding a dynamic characteristic to complexity that might easily fit construction projects.

On the other hand, Kahane (2004) takes a social networking view, suggesting that complexity arises from differences in perspectives and interests; where cause and effect gaps are wide; where problem solutions are not necessarily found in advance; and where people must participate in dealing with them. This also reflects construction processes.

Stacey (1996) offers complexity as two dimensional: certainty and the measure of agreement between constituents; and proposes that the relationship between them might reflect situations ranging from “simple” to “anarchic”. This proposition stems from the antecedents of complexity science in chaos theory, which proposes how meaningful order is found among chaotic systems, and conversely how extensive networks and behaviours can arise from simple ideas and connections. In construction we are probably reluctant to consider construction projects as lying at either end of the continuum, but it may be worth remembering that “complex projects” might not be far from the right-hand extreme!

Complex systems may be static (fixed in place, as in a rules-based administrative system) or dynamic (subject to change over time), and the latter may be self-organising (as in some natural systems) or imposed. From a systems viewpoint, construction projects probably lie in the dynamic imposed category. In order to explore and assess complexity in projects, a model or framework is thus needed, and Snowden and Boone (2007) created a “Cynefin” *sense-making* framework which essentially re-organises Stacey’s earlier model into scenario quadrants categorised as: Simple; Complicated; Complex; and Chaotic. Note how “Chaotic” in this model sits close to the “anarchic” measure suggested by Stacey and reflects its antecedents.

Complex projects

Baccarini (1996) and Williams (1999; 2002) propose that, conceptually, the complexity of a project is influenced by the *level of uncertainty* associated with two states relating to its constituent elements and sub-elements (parts). These states are the conditions of *differentiation* and *inter-dependency.* Differentiation refers to the number of constituent parts distinguishable – or needing to be distinguished - in a system (project). Inter-dependency arises in the extent and nature of relationships occurring between the differentiated parts. Uncertainty may be associated with either or both states.

Senescu, Aranda-Mena and Haymaker (2013) point to vital role of communication in managing complex projects. We emphasise that this will include intra-organisational as well as inter-organisational communication. People within construction organisations need to share an understanding of project complexity in order to make robust decisions. Project complexity also has a psychological dimension, in that decision-makers tend to perceive it in terms of their intellectual and mental capacity to deal with it (Mikkelsen, 2020). This background provides sufficient understanding to allow us to conceptualise an early-stage tool for assessing project complexity.

A conceptual early stage project complexity assessment tool

Our proposed ***P***roject ***E***arly ***S***tage ***C***omplexity ***A***ssessment ***T***ool (PESCAT) brings together Baccarini (1996) and Williams (1999), Kahane (2004), Stacey (1996) and the Snowden and Boone (2007) Cynefin framework, with at least part of the Remington and Pollock (2007) approach. In its first iteration (Mk1) PESCAT considers the project solution space and the project decision making that accompanies it, together with their associated uncertainties. Conceptually, PESCAT application requires experiential judgment, reflective risk wisdom (since project decision-making inevitably involves uncertainty and therefore risk) and the capacity to intellectually (and even emotionally) coalesce several influencing factors. For example, in dealing with complexity, conflicts can arise between the process flexibility needed for high levels of uncertainty and the requirements (and expectations) for efficient performance. The project complexity assessment tool format is depicted in Figure 1.

In applying PESCAT Mk1, users first identify the project and the project stakeholder for whom complexity is being assessed. The project phase is also chosen. Four project lenses (or perspectives) are suggested for assessment: (a) the governance or organisational structure for the project; (b) the range of tasks or activities the stakeholder will carry out; (c) the technologies involved; and (d) the organisation/management that stakeholder will need to undertake the project. Five-point rating scales are applied to each lens: Very Low; Low; Moderate; High; Very High.

For each lens/perspective the "Resolution Space" is first assessed (vertical axis). This is an amalgam of solution space (as proxy for differentiation) and the degree of perceived difficulty with its associated decision-making. The horizontal axis rates the amount of "Uncertainty" associated with the Resolution Space. A stakeholder applying PESCAT must first, as a matter of strategic management, allocate the five levels of project complexity (Simple; Slightly Complex; Complex; Highly Complex; and Chaotic) into the cells in the upper grid. The tool concept is then ready for proof-testing.

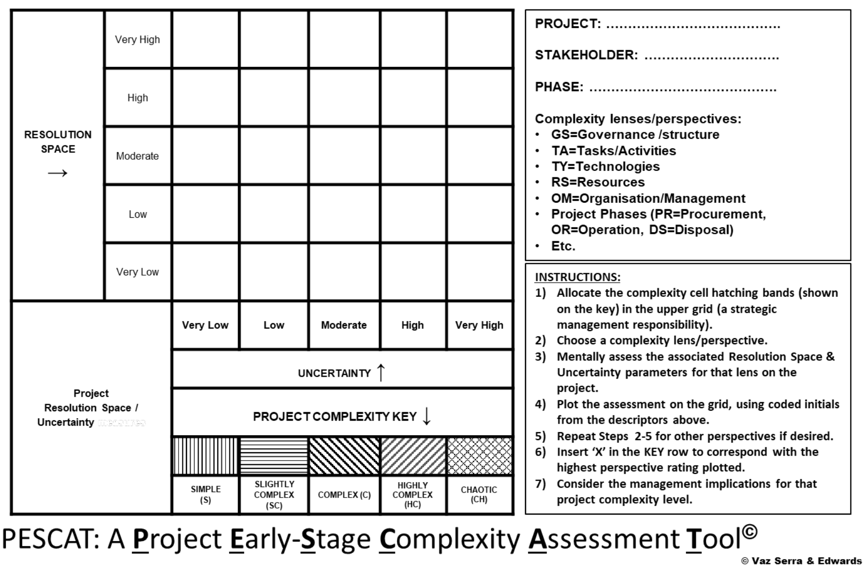

Fig.1. Format for the proposed project complexity assessment tool.

Research method

We adopted a mixed methods approach for the concept-proofing research. Following the PESCAT design, focus group workshops were held at the University of Melbourne in February 2020. Since complexity is to some extent a "lived" experience, focus groups were deemed appropriate for the purpose. The A workshops (duplicated to meet participant needs) were followed by Workshop B in early March 2020

Convenience (industry contacts known to the researchers) and snowball methods were used to invite participation from construction industry professionals working in the Melbourne area. In Workshop A (held on a midweek evening from 5.30 – 8.15pm on two successive weeks), the PESCAT concept was presented by the researchers. Participants then completed the questionnaire survey, mostly following a "circle your choice(s)" answer entry format.

Following completion of the survey, participants applied PESCAT Mk1 to three case studies taken from real-life projects known to the researchers, each presented as a slide of the project organogram accompanied by verbal descriptions.

Case Study 1 is an Australian correctional facility (approximate construction value AU$600 million) procured under a Public Private Partnership arrangement. Case Study 2 is an improvement programme across a metropolitan rail system, valued at more than AU$8 billion, and procured as eleven packages under Alliance or Design & Construct contracts. Case Study 3 is a foreign aid-funded project for a new civic facility (costing about AU$40 million) for a Pacific Rim island national government, procured under traditional separated design/construction.

Using the PESCAT Mk1 grids, Workshop A participants were asked to assess (individually or in small groups) the complexity of each case study project. This involved first allocating the five project complexity levels (Simple; Slightly Complex; Complex; Highly Complex; Chaotic) into the cells of the main grid. This allocation represents a strategic management decision. Participants then chose a project perspective from the list shown on the template; and subjectively assessed the resolution space (solution space differentiation and associated interdependency) and the associated uncertainty for that perspective (using 5-point scales from Very Low to Very High). They mapped their assessments onto the project grid, thus arriving at a complexity level for that perspective for that project; and then repeated the process for other perspectives. The perspective assessment which mapped into the highest complexity level cell thus indicated the overall complexity level for that case study project.

Workshop participants then repeated the whole process for the next case study. While some groups assessed only one project, others managed to do two assessments, and a few completed assessments for all three case projects. It was observed that the more projects groups assessed, the faster their assessments were completed.

At the conclusion of the workshop, additional PESCAT grids were handed out and participants were asked to take them away, apply them to current or historical projects in their own organisations, and return the completed complexity assessments to the researchers.

Workshop B was used to present the preliminary results of the survey analysis; allow discussion of these findings; and permit handing-in of any takeaway project assessments not previously submitted via email. Following the premature discussion referred to earlier during Workshop A, and survey responses to Question 9, a modified version of PESCAT (Mk2) was presented for discussion; and reflective comment on the concepts elicited. Feedback forms (about the workshop processes) were also given to participants for completion before formally closing the proceedings.

Results

Demographic characteristics of participants

The professional disciplines and age characteristics of workshop participants are shown in Table 1.

All participants were male. Female construction professionals were invited, but all those who initially accepted subsequently cancelled. The workshop timing (5.30 – 8.15pm on a midweek evening) may have influenced this. Apart from this, the workshop group is considered reasonably representative of the Australian construction industry, particularly with regard to experience.

Table 1. Workshop participant demographics.

Profession	***n***	**<30yo**	**31-40yo**	**41-50yo**	**51-60yo**	**>60yo**
Architect	3			3		
Civil Engineer	4			1	1	1
Construction Manager	1			1		1
Project Manager	6		2	1	1	2
Quantity Surveyor	1			1		
Safety Officer	1					1
Totals:	16	0	2	7	2	5

Workshop A: PESCAT Mk1 presentation

The presentation of PESCAT Mk1 in Workshop A attracted some comment and discussion, mainly concerning participant difficulty in grasping the tool concept, the validity of the tool assessment parameters (especially "Resolution Space"), and the need for project stakeholders to make individual project complexity assessments. Some resistance was expressed or detected in Workshop A to the use of "Chaotic" as a project complexity descriptor. Participants agreed to defer fuller discussion of these issues until Workshop B, after they had applied PESCAT in several project circumstances.

Workshop A: survey questionnaire responses

About two thirds of participants (10) thought that construction projects *best reflected complex behaviour that emerges from simple underlying rules* (Q2; dichotomous), although some support was shown (from architects) for the alternative view that complexity *is about how order and patterns arise from apparently chaotic systems*. Respondents were unanimous (16) in thinking that construction projects are best represented by *dynamic systems* and about half also reckoned that such systems were *imposed rather than self-organising* (Q3). All respondents thought that assessment of project complexity was *important* (Q4: dichotomous). For Q5 (seven options), seven respondents selected option (c) "Business case/feasibility stage" as the *best stage in the project development life-cycle to assess complexity*. Five chose (a) "Concept proposal stage"; while 3 selected (b) "Concept development stage". One project manager opted for (d) "Design proposal stage".

For Q6 (seven benefits offered), the *potential benefits of project complexity assessment* were perceived (in frequency count order) as: "assigning appropriate management" resources (14); "establishing appropriate budgets and establishing an appropriate tender/offer price" (13); "establishing appropriate administrative systems" (12); "better time scheduling" (11); "establishing training requirements" (9) and "better unit pricing for project activities"(8). Participants thus thought that multiple benefits could be achieved, and some suggested further benefits: "better risk management" (4); "establishing key interfaces" (1); "better project briefing" (1); "better organisational resourcing" (1); "minimising waste" (1); "aligning complexity and commitments" (1); plus a "wider benefit in terms of end value and society" (1).

Q7 explored factors (thirteen taken from listed PMBoK processes) that might influence project complexity. In rank score order of importance ratings (five interval scale with only extreme ends 'Not important' and 'Highly Important' labelled), survey participants selected: "project risks" (73); "project cost and project communications" (68); "project scope" (67); "project procurement" (66); "project integration" (64); "project quality" (63); "project timing and project safety" (63); "project finance" (62); "project HR and project environment" (56) and "project claims" (52). Additional contributory factors were specified and invited in Q8. Importance scores (using the five-interval scale described above) for the three listed factors were: “Stakeholder management” (69); “Technology management” (51); and “Procurement systems” (48). Survey participants also offered additional contributory factors (without importance ratings): “project interfaces”; “people”; “organisational styles”; “organisational structures”; “supply chains”; “design”; “detailing”; “contracting”; “co-ordination”; “political climate or risks” (3 participants); “environmental risks”; “design management” (2 participants); “sequencing”; “work methods”; “project location”; “interdependencies”; “client type”; “previous experience with that client”; and “global events”.

Q9 tested the PESCAT concept directly (three complexity measures stated; four agreement options offered). Eleven participants agreed with the Resolution Space/Uncertainty tool parameters for assessing project complexity. One totally agreed and three somewhat disagreed. Comments included requests for better parameter definitions (3 participants), more examples, and a query about how PESCAT would fit into the project management process.

Data analysis for Q10 (participant allocation of five complexity levels into a grid) was not completed in time for Workshop B. For Q11, frequency counts for the five options listed about how project complexity is dealt with in participants’ organisations were: “No specific action” (0); “Informally by senior management” (8); “Formally by senior management using procedural guidelines” (4); “Informally by project/construction managers, etc.” (2); “Formally by project/construction managers using proformas” (4). One participant indicated that complexity is addressed as part of project risk management. In Q12, complexity knowledge management was explored by offering six options, and the selection frequencies for survey participants were: “Not at all” (0); “Left as individual staff wisdom” (2); “Informally among key staff groups” (5); “Semi-formally through meeting agendas and minutes” (7); “Formally through dedicated briefings, de-briefings and reports” (4); and “Integrated into a searchable organisational Knowledge Management System” (2).

Discussion

The Workshop A survey confirmed that an informed assessment of project complexity is important and beneficial, particularly if carried out as early as possible in the project development stage. While some workshop participants had initially expressed a view that a universal assessment was desirable (ie, by all stakeholders for a project) this view changed after they had applied PESCAT Mk1 to the case study projects and after they reflected that the placement of complexity level labels in the assessment grid was a strategic management responsibility for each stakeholder.

Further development of PESCAT was indicated, especially in terms of the measures of project complexity (Q9). Refinement of the list of contributory factor options also appeared desirable, given the response scores to Q7. For PESCAT Mk2, a closer proxy to the Baccarini (1996) and Williams (1999) differentiation and interdependency approach was adopted as a dual measure on the vertical axis; and uncertainty and decision difficulty as a dual measure for the horizontal axis. The practicality of the Mk2 tool development was tested in Workshop B and while its greater practicality was acknowledged, workshop participants remarked that it was still difficult to grasp the assessment measures of the tool concept intellectually.

Tool development has since progressed to PESCAT Mk5 (Figures 2a and 2b). Four distinct assessment measures are now proposed, a revised menu of project perspectives has been adopted, and guidelines for use have been improved. This version also allocates project complexity levels into the grid based upon a “normalised” distribution derived from all the workshop and private assessments carried out by the research participants. The decision-making parameter has been subsumed into the differentiation and interdependency measures, since they are inherently associated with making project decisions.

PESCAT should be used as early as possible in the organization's involvement with a project. Assessment should be carried out by a small group (3-5) of appropriately experienced staff in the organization. Practice with old projects is recommended. When used properly, the overall level of project complexity will be better understood, together with the project perspectives that are most influencing it.

APPLICATION GUIDE:

1) Nominate the project.
2) Nominate the project stakeholder for whom the complexity assessment is being conducted.
3) Nominate the project phase that is to be assessed.
4) Choose an appropriate project Perspectives Set to apply. Add further perspectives to a set if required, or create a new set tailored for your organization.
5) For one Perspective, and using the ratings from Very Low to Very high, SUBJECTIVELY assess the DIFFERENTIATION (the number of identifiable separate parts for that perspective) as Measure A, and any UNCERTAINTY associated with that Differentiation as Measure B.
6) Again using ratings from Very Low to Very High, SUBJECTIVELY assess the INTERDEPENDENCY (the extent of the inter-relatednesss between differentiated parts as Measure C, and the UNCERTAINTY associated with the Interdependency for that project perspective as Measure D.
7) Using the coded initials from the perspective descriptors in the table, plot the highest of the four ratings for that perspective onto the assessment grid.
8) Repeat Steps 5-7 for other project perspectives in the set.
9) Insert 'X' in the Complexity Key row (at the bottom of the grid) to correspond with the upper grid cell complexity level label for the highest perspective rating plotted for that project phase.
10) You should now have better understanding of the level of complexity for that perspective and the aspects that are most influencing the complexity.
11) Consider the management implications for that level of complexity for that project perspective. For example, project perspectives exhibiting higher levels of interdependency uncertainty are likely to be associated with higher levels of risk and this may guide risk identification and management processes. Also, knowing which of the four measures (ie Differentiation or Differentiation Uncertainty, and Interdependency and Interdependency Uncertainty) is rated more highly can help in exploring project management options.
12) Repeat Steps 3-11 for other project phases if required.

PROJECT:			
STAKEHOLDER:			
PROJECT PHASE:	**DELIVERY / OPERATIONAL / DISPOSAL**		
Perspectives Set A	**Perspectives Set B**	**Perspectives Set C**	**Perspectives Set D**
Project Governance/structure (GS)	Project integration (PIN)	Technical systems (TS)	
Project Organisation (PO)	Project scope (PSC)	Design concept (DC)	
Project Resources (RS)	Project schedule (PSH)	Spatial distribution planning (SD)	
Project Tasks/Activities (TA)	Project cost (PCS)	Schematic design (SCM)	
Project Technologies (TY)	Project quality (PQY)	Services & systems integration (SVS)	
	Project design (PDS)	Documentation & tendering (DTD)	
	Project health & safety (PHS)	Contract award (CWD)	
		Supervision (SVN)	
		Commissioning & Handover (CMN)	
		Operational manuals & software (OPS)	
Notes:			

Fig.2a. PESCAT Mk5 Application guide.

		Measure B: DIFFERENTIATION UNCERTAINTY →					↑ **Measure C:** **INTERDEPENDENCY**
↑ **Measure A:** **DIFFERENTIATION**	**Very High**	C	C	HC	EC	EC	
	High	SC	C	C	HC	EC	
	Moderate	SC	SC	C	HC	HC	
	Low	S	S	SC	C	HC	
	Very Low	S	S	SC	C	C	
PROJECT COMPLEXITY ASSESSMENT		**Very Low**	**Low**	**Moderate**	**High**	**Very High**	
Ref: ……………… Date: ……..		**Measure D: INTERDEPENDENCY UNCERTAINTY →**					
PROJECT: ……………………………………..		**PROJECT COMPLEXITY LEVEL KEYS ↓**					
STAKEHOLDER: …………………………………….		**(S)**	**(SC)**	**(C)**	**(HC)**	**(EC)**	
PROJECT PHASE: ……………………………………. ASSESSMENT PERSPECTIVES SET: …… ASSESSORS: ………………………………..		**SIMPLE**	**SLIGHTLY COMPLEX**	**COMPLEX**	**HIGHLY COMPLEX**	**EXTREMELY COMPLEX**	

Fig.2b. PESCAT Mk5 Tool format

After selecting (or creating) a project perspective set, the user makes four qualitative assessments for each factor in turn. The first is for project differentiation (Figure 2b: Measure A); followed by uncertainty associated with differentiation (Measure B). Measure C assesses the extent of inter-dependency associated with the differentiation, and Measure D the uncertainty relating to the inter-dependency. Thus, for a five-factor set of project perspectives (Fig.2a: Set A), twenty subjective assessments are made and plotted on the project grid. Although this may seem a complicated process, in practice it is quite easy and rapid. It also emphasises uncertainty as a major contributor to project complexity.

PESCAT users can choose (or create) a set of project perspectives that best represents their individual involvement in the project. Designers might wish to follow their design process; while contractors would make assessments according to the construction processes. Project managers could tailor a set of perspectives related to their management activities. The conceptual acceptability of PESCAT Mk5 has still to be fully tested in practice, but informal consultation with a few workshop members indicates that it would now form a useful tool in their project management armoury.

Conclusions

The concept proof-testing research has shown that project complexity assessment at an early stage is not only desirable, but also beneficial for stakeholders directly involved in a project. Having a better understanding of the nature and extent of project complexity informs decision-making and allows better targeting of resources.

PESCAT can be used for this assessment, provided it is based upon factors that strategically and meaningfully contribute towards, or influence, complexity for that project for that stakeholder. Tool application is best done by a small group of experienced construction professionals. The PESCAT Mk5 version assesses four dimensions of complexity for a selected set of project perspectives: project differentiation and its uncertainty; and differentiation inter-dependency and its uncertainty. PESCAT then provides an overall level of complexity for a project and can indicate the strength of contributory factors. Senior management can use this information to make more nuanced decisions about resource allocation and scheduling.

As a qualitative tool based upon subjective assessments of project factors, PESCAT may be subject to personal bias, but the small group application should guard against this. Periodic re-calibration, using historic project data, would also mitigate this risk. Further research will test the latest version of PESCAT; and gather additional feedback about its use in practice. The mixed methods research approach has also shown that concept-proofing propositions in this way is a valid, practical and inexpensive means of testing new ideas in project management.

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