A Research Agenda for Embedding 4IR Technologies in the Leadership Management of Formal Methods[1]

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***Abstract*— The use of Formal Methods (FMs) in software development holds much promise for constructing provably correct, or at least highly dependable software. That said, the use of such techniques remains controversial – advocates of the use of FMs cite high-quality software as a major selling point, while critics point to the steep learning curve in acquiring the necessary mathematical skills. In this paper we investigate aspects around ambiguity of semi-formal specifications with respect to the Quality 4.0 framework. Following these we argue that the opportunities in the Fourth Industrial Revolution (4IR) coupled with leadership-management support may facilitate the use of FMs as a software methodology, not only for mission-critical software, but equally for Business ICTs. Following our analyses, we propose a research agenda for investigating the leadership-management, FMs and 4IR triad, aimed at facilitating the adoption of FMs in the new industry.**

Keywords*— *Artificial intelligence (AI), Formal methods (FMs), Fourth industrial revolution (4IR), Formal specification, Governance, Leadership-Management, Research agenda, Software development methodology.

I. Introduction

The use of Formal Methods (FMs) in software development holds much promise for constructing provably correct, or at least highly dependable software [1]. While FMs use is associated most often with the development of safety- or mission critical systems where human life is at stake, it may equally well improve the quality of other applications, for example Business ICTs [2]. The use of FMs as a methodology embodies sequential and sometimes iterative development of a formal specification from a requirements definition or a UML-like specification. The formal specification is then exercised by reasoning about its properties, illustrating desirable properties of the specification and at the same time showing that undesirable consequences cannot be derived. The resultant specification is usually refined into an executable computer program [3].

Despite their value as a software development methodology, the uptake of FMs, specifically in business software remains low [4]. In response to this state of affairs, the promises and opportunities of the Fourth Industrial Revolution (4IR) with respect to Artificial Intelligence in FMs, intelligent simulations (to assist with reasoning about the specification), cloud- or edge computing coupled with the Industrial Internet of Things (IIoT), smart manufacturing [5] and blockchain to name just a few should be investigated to facilitate the use of FMs as a feasible software development methodology. While initial attempts have been made in standards for FMs use, for example the Formal Methods Body of Knowledge (FMBoK) [6], these should be enhanced to incorporate specifics with respect to 4IR opportunities. Some 4IR frameworks, for example Quality 4.0 are around, but suffer from ambiguity when attempting to apply a formal methods approach to it. Amongst other things, therefore, 4IR-FMs frameworks should be researched.

In addition to the above technical challenges, the role of governors – leadership managers in supporting the use of FMs at a higher level should be investigated. Apart from initial work done on the role of FMs for management [7], the upper-management support for these is largely lacking. In the governance and leadership fraternity, 4IR frameworks in the form of Leadership 4.0 [8] have been defined and it is anticipated that corresponding triads for leadership-management, FMs, and 4IR opportunities may be developed.

In this paper, following an interpretive research strategy, coupled with an inductive research approach and a mixed qualitative and semi-quantitative research choice, the researcher develops a multi-level research agenda for leadership support for utilising the promises of the 4IR in an ongoing adoption of FMs. As part of the interplay between leadership and management, cognisance is given to the role of the Chief Information Officer (CIO) or Chief Digital Officer (CDO) as managers, reporting to the Chief Executive Officer (CIOs) as a leadership component.

The layout of the paper is: Following the introduction the research questions and objective underlying this research are presented next. Our research methodology is defined in the form of a literature review on aspects around semi-formal specifications and formal specification techniques. Governance considerations in the form of leadership-management are discussed, followed by components of the 4IR. A research agenda is defined in the form of a multi-level table, and it is briefly theoretically validated. The paper presents a conclusion and future work in this area, followed by a list of references.

A. *Research Questions and Objective*

The research questions addressed in this work are:

- What are the advantages and disadvantages of using semi-formal notations and formal notations? (RQ1)
- What may be the role of leadership-management in the adoption of FMs? (RQ2)

Our objective is to:

- Develop a research agenda to address the above research questions.

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II. Literature Review

Our literature review considers ambiguity in semi-formal specifications through an analysis of the Quality 4.0 framework, followed by examples and analyses of formal notations; and discussions on governance, leadership, management aspects, and components of the 4IR.

A. Semi-Formal Specifications

Traditionally, users mostly prefer natural-language or semi-formal specifications for software systems [9] owing to their familiar, every-day notations involving diagrams and text. Despite their visual attraction, diagrams may suffer from ambiguity [10]. Modern fourth-industrial revolution constructs may likewise suffer from ambiguity, for example, the ambitious Quality 4.0 framework discussed next.

1) Analysing the Quality 4.0 framework

Many traditional frameworks in the third industrial revolution characterised by the use of modern Information and Communications Technologies (ICTs) have been enhanced to take cognisance of the Third Industrial Revolution (3IR) that started in the late 1900s with the advent of electronics, nuclear energy and, of course, Information and Communications Technologies (ICTs). These led to the fourth industrial revolution (4IR) [11] discussed later in this paper.

The Quality 4.0 framework [12] incorporates traditional (3IR) quality at its core as indicated in Figure 1.

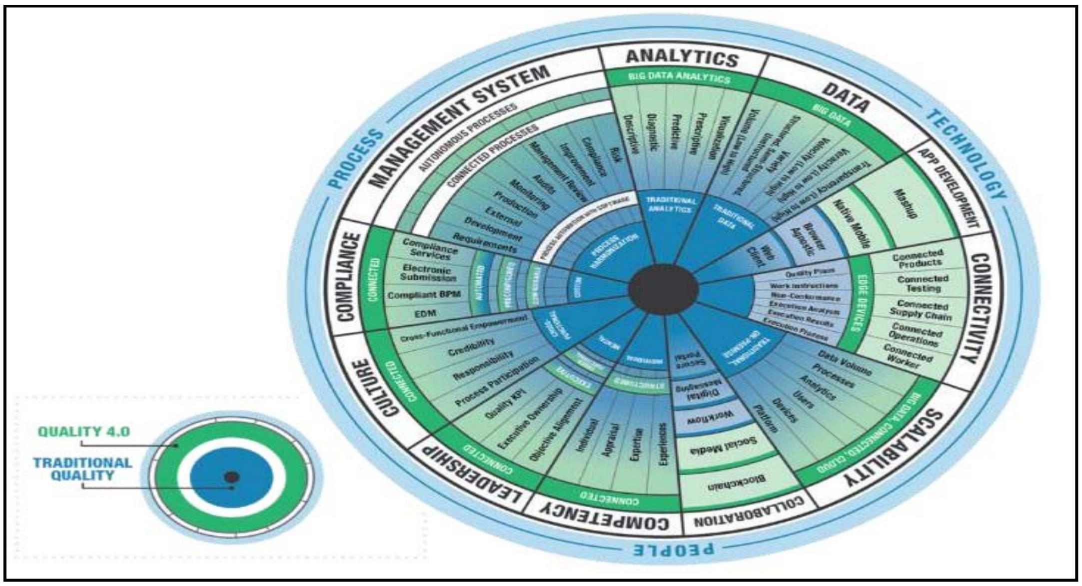

Figure 1: Quality 4.0 Framework (source: [12])

Quality 4.0 embodies three aspects: PEOPLE, PROCESS(ES), and TECHNOLOGY at its outer rim. On the inside it's based on 11 pillars – *Analytics, Data, App Development, Connectivity, Scalability, Collaboration, Competency, Leadership, Culture, Compliance, and Management System(s).* Since analytics is such an integral component of the 4IR we attempt a formalisation of the *Analytics* pillar.

As per Figure 1 there appears to be a one-to-one mapping between *Analytics* and *Big Data Analytics* at the next layer. This poses the question whether Analytics in the 4IR is necessarily the analysis of Big Data? This may be the case, but it could be the same bias as e.g., claiming that technology is necessarily just ICT. Nevertheless, it gives rise to our 1st ambiguity:

- *Analytics ≙ Big Data Analytics*

Ambiguity #1 (an assumption)

Next, we observe that *Big Data Analytics* is made up of five subsectors – *Descriptive*, *Diagnostic*, *Predictive*, *Prescriptive* and *Visualization*. Semantically we already note a discrepancy in the denotations, e.g., "Descriptive" is an adjective and so are some others, but "Visualization" is a noun. Next, we note there may be an ordering among the five sectors, i.e., these may be described by a Cartesian product:

- *Big Data Analytics ≙ Descriptive* × *Diagnostic* × *Predictive* × *Prescriptive* × *Visualization*

Alternatively, no ordering may be inferred in which case these may form a (an unordered) set. Presumably no ordering is implied, leading to our 2nd ambiguity:

- *Big Data Analytics* ≙ set of *X*, for
- *X* = {*Descriptive, Diagnostic, Predictive, Prescriptive, Visualization*}

Ambiguity #2 (an assumption)

Next, we have a layer called *Traditional Analytics* and again it's not clear whether each of the above five subsectors embodies traditional analytics, or whether they collectively define traditional analytics. Suppose each exhibits a traditional component. Then we refine set *X* above:

- *X* = {*Descriptive.Traditional_Analytics, Diagnostic.Traditional_Analytics, Predictive.Traditional_Analytics, Prescriptive.Traditional_Analytics, Visualization.Traditional_Analytics* }

Ambiguity #3 (an assumption)

Consequently, an attempt at formalising one of the 11 pillars of Quality 4.0 led to three ambiguities. We note that a formalisation of the *Leadership* pillar in [13] led to a set of different ambiguities.

The analysis of the Quality 4.0 framework illustrates some of the challenges associated with diagrammatic or semi-formal notations. Consequently, researchers have been calling for the use of formal notations, embodying, for example, discrete mathematics and logic [14].

We note that Quality 4.0 was probably not designed with formality in mind. Rather it is intended as a high-level guide to be instantiated for each application.

The above discussions yield a partial answer our 1st research question, RQ1.

B. Formal Methods in Software Engineering

The analyses of Quality 4.0 illustrated the value of computing formalisms, yet FMs sometimes exhibit challenges of their own as we illustrate next.

The use of FMs in software development usually involves a formal specification as a starting point, followed by an iterative process of reasoning about the properties of the specification, reworking the specification, and finally refining the specification into high-level code (Java, C, etc.). Consider a fragment of a Z [15] specification of a car registration system whereby an owner registers a car and defers payment of the registration fee to a later stage (example adapted from [16]).

Schema *Car_Register* registers a car, without any payment.

$$\begin{array}{|l} \multicolumn{1}{l}{\mathit{Car\_Register}} \\ \hline \Delta\, \mathit{Registration\_System} \\ c? : \mathit{Car} \\ \hline c? \notin \mathit{registered\_cars} \\ \mathit{registered\_cars}' = \mathit{registered\_cars} \cup \{c?\} \\ \mathit{registration\_payment}' = \mathit{registration\_payment} \\ \hline \end{array}$$

The system receives as input the registration number of a car (*c?*) to be registered. There may be a change in the state of the system, indicated by Δ *Registration_System*. The car is not in the system already; it is added to the system and no payment is made, indicated by the *registration_payment* component of the system to remain invariant (*registration_payment′* = *registration_payment*).

Schema *Car_Pay* below captures a payment.

$$\begin{array}{|l} \multicolumn{1}{l}{\mathit{Car\_Pay}} \\ \hline \Delta\, \mathit{Registration\_System} \\ c? : \mathit{Car} \\ \mathit{amount}? : \mathbb{R} \\ \hline c? \in \mathit{registered\_cars} \\ \mathit{registration\_payment}' = \\ \quad \mathit{registration\_payment} \cup \{c? \mapsto \mathit{amount}?\} \\ \mathit{registered\_cars}' = \mathit{registered\_cars} \\ \hline \end{array}$$

Real numbers (ℝ) are not part of standard Z (being a discrete system), but suggestions for a real-number toolkit for Z are presented in [17].

Using Z's schema calculus, we may now combine the two schemas to capture the complete picture whereby an owner registers a car and effects a payment, viz.:

$$\mathit{Car\_Register\_and\_Pay} \mathrel{\widehat{=}} \mathit{Car\_Register} \wedge \mathit{Car\_Pay}$$

Schema *Car_Register_and_Pay* is given by:

$$\begin{array}{|l} \multicolumn{1}{l}{\mathit{Car\_Register\_and\_Pay}} \\ \hline \Delta\, \mathit{Registration\_System} \\ c? : \mathit{Car} \\ \mathit{amount}? : \mathbb{R} \\ \hline c? \notin \mathit{registered\_cars} \wedge c? \in \mathit{registered\_cars} \\ (\mathit{registration\_payment}' = \mathit{registration\_payment} \wedge \\ \quad \mathit{registration\_payment}' = \\ \qquad \mathit{registration\_payment} \cup \{c? \mapsto \mathit{amount}?\}) \\ (\mathit{registered\_cars}' = \mathit{registered\_cars} \wedge \\ \quad \mathit{registered\_cars}' = \mathit{registered\_cars} \cup \{c?\}) \\ \hline \end{array}$$

Car_Register_and_Pay displays inconsistencies and illustrates an aspect around one of the dark corners of Z [18]. Consequently, care has to be exercised in the writing of a formal specification. This is why we in the above describe the development of a formal specification as an iterative process of specification followed by reasoning about the specification. Numerous reasoners, e.g., Vampire [19] and Event-B/Rodin [20], some automated, some interactive, and some a blend of the two modes are available for this task.

The discussions in the preceding sections answer RQ1.

C. The Role of Leadership Management in FMs Usage

While the use of FMs in software development may lead to correct, or at least highly dependable software, its use as a software development methodology is often met with opposition. Advocates of FMs point to the benefits to be realised for safety- or mission-critical software where human life may be at stake, for example, software that drives a nuclear power plant, or a cancer radiation machine [21]. Those not in favour of the use of FMs point to the steep learning curve in acquiring the necessary mathematical skills to use an FM effectively [22].

The Quality 4.0 framework above gives cognisance to the role of Leadership as one of the 11 pillars. Such leadership as a quality pillar may be mapped to the quality of software, i.e., correct, and reliable software. Further down in the leadership sector are cross functional and executive leadership which could be mapped onto differences between management and leadership.

Leadership is generally considered to be leading people towards a common visionary goal while management may be viewed as overseeing the execution of tasks aimed at achieving the visionary goal of the leader. Forward planning and strategic thinking are viewed as part of leadership, while again, the planning and delegation of implementing these are part of management [23, 24]). In this regard, leadership and governance are often spoken about in the same context, namely, visionary goals; and appointing and overseeing management. For the purposes of this paper, we view governance as *Leadership Management,* and it is reflected accordingly in the research agenda developed in this work.

The adoption or not of FMs as a software development methodology in a company may ultimately boil down to a leadership vision of developing high quality software products. If such leader sees value in the use of these techniques, managers may be tasked to execute such vision and look for ways to successfully implement these in the said company. Executing a cross-functional leadership vision under the auspices of executive leadership would then have the Chief Executive Officer (CEO) of the company motivate the software developers via the Chief Information Officer (CIO) or Chief Digital Officer (CDO) to embark on the use of FMs for software development.

Integrated with the above would be considerations around adoption and ongoing use (post adoption which involves aspects of sustainability) of FMs in software development. Various technology adoption models, e.g., Technology Acceptance Model (TAM), Unified Theory of Acceptance and Use of Technology (UTAUT) [25], or Technology Organisation Environment (TOE) [26] could be utilised to work towards fulfilling the vision of the leader.

The researcher notes that autocratic leadership styles in which the use of FMs for software development is enforced as a methodology may, despite the advantages of FMs compromise sustaining good software development practices in a company. Consequently, a very fine balance between handing down the vision of a leader and allowing developers sufficient freedom, should be exercised. Naturally, aspects around the role of subordinates, employee autonomy and organisational culture come into play.

Reference [7] provides some pointers for management to embark on FMs for software development. Chief among these are: initially make use of an expert, coupled with the services of one or more consultants; liaise with early adopters of technology; augment traditional processes with FMs, not replace them; decide on which phase in the SDLC to use the FM; invest in good support tools; and conduct a thorough risk analysis and the return on investment (ROI) for these. Our research agenda proposed in this paper takes cognisance of these aspects.

D. Leadership 4.0

In response to 4IR demands, Leadership 4.0 frameworks have been proposed. A four-layer leadership 4.0 framework is proposed in [8], while [27] suggests Leadership 4.0 to embody 10 leadership aspects, namely, digital, collaboration, responsiveness, swarm (intelligence), learning and innovation, openness, agility, participation, networking, and trust. Our research agenda likewise considers Leadership 4.0 aspects.

The discussion in this section provides an answer to RQ2.

E. The Fourth Industrial Revolution (4IR)

The 4IR originated in Germany between 2011 and 2015 during which such notion was first coined by Klaus Schwab [11]. The 4IR, following on the 3IR blurs the divisions among physical, biological (human) and digital worlds. In this new world, humans and machines are anticipated to work closely together, with the possibility of robots being promoted from mere repetitive-task production machines to managers and even governors in the future [28], leading to numerous ethical issues in such collegialism.

Numerous 4IR frameworks, for example, Leadership 4.0 and Quality 4.0 discussed above have been developed. Further aspects involved with the 4IR include Artificial Intelligence (including machine learning and reasoning), the (Industrial) Internet of Things (I)IoT in which devices can connect to, and communicate with each other over the Internet, Printing 4.0, generally known as 3D-printing, Intelligent Simulations, Augmented Reality/Virtual Reality (AR/VR), and Additive Manufacturing (AM) to name but a few [29]. Intelligent (artificial) reasoning and simulations hold much promise for the reasoning about, and execution of formal specifications, hence these aspects deserve a place in our research agenda.

III. Towards a Research Agenda

Numerous aspects emerge from the foregoing discussion on the interplay among leadership management, technology adoption, the use of FMs for software development, and the fourth industrial revolution.

The researcher observed over the course of three decades that management buy-in into any worthwhile endeavour is vital to facilitate the success thereof. This sentiment is likewise echoed by [7]. The use of FMs initially increases the cost and development time during the early phases of software development, but this initial investment pays off later, in that the overall cost of the project is reduced. It should be noted that automated techniques brought about by the 4IR have the potential to shorten development time and costs of even the early phases of software development.

Our research agenda for developments in leadership management, FMs and the role of the 4IR is presented as a multilevel structure embodied in Table 1.

Table 1: Research Agenda - Leadership Management of FMs in the 4IR

GOVERNANCE – LEADERSHIP MANAGEMENT				
Executive Leadership		**Cross-Functional Leadership**		**Fourth Industrial Revolution**
LEADERSHIP	**ORGANISATIONAL CULTURE**	**MANAGEMENT**	**LEGISLATION**	**4IR ASPECTS**
Vision	Level of Autonomy	Tasks	Policies	Artificial intelligence
Strategy	Ethics for Robots	Adoption of FMs as a	*Professional*	Intelligent simulations
Inspiration	Views of developers	Technology	*Status for FMs*	(Simulation 4.0)
Direction	versus	TAM/UTAUT/TOE	*developers*	(I)IoT
Goals	Leadership	CIO/CDO tasks	*Correct software*	AR/VR
Professional status	Management	**FMs Considerations**	*development*	Additive manufacturing
for correct	Leadership styles	Formal specification		Automation
software	* Autocratic	Techniques/styles		(Development)
development	* Democratic	Tool support		Tool support
Technology buy-in	* Consultative	Reasoners		Quality 4.0

GOVERNANCE – LEADERSHIP MANAGEMENT				
Executive Leadership		Cross-Functional Leadership		Fourth Industrial Revolution
by Employees *Leadership 4.0*		* Automated * Interactive * Hybrid Expert advice Augmentation of FMs with traditional processes Risk analysis ROI FMs Standards (FMBoK) Best practices (BPs)		*Leadership 4.0*

Source: Synthesised by researcher.

A. Validation of the Research Agenda

Our Table 1 research agenda takes cognisance of the developments in this paper. The view of governance as leadership management is acknowledged as the preface to the agenda. Executive leadership gives guidance and vision to the company with management indicated as a cross-functional, and task-driven aspect in executing the vision of leadership in the second layer of the agenda. Owing to its importance and anticipation as a driving force in facilitating the adoption of FMs, 4IR aspects are given prominence in the agenda.

Our agenda is enhanced through considerations around executive leadership, cross-functional management, especially the role of the CIO or CDO in facilitating the adoption of FMs, and the 4IR aspects that may facilitate tool support for FMs usage – AI and intelligent simulation to validate the correctness of a formal specification.

Leadership styles versus the autonomy of software developers are bound to become important considerations, especially with the possibility of robots becoming managers and even leaders in the 4IR. The ethical principles according to which these machines operate will be vital. A further important point is that FMs are viewed as a technology which could be adopted or rejected, hence technology adoption frameworks on these may have to be further developed.

One may think that tool support coupled with the reasoning component of reasoners would be pretty much sorted in modern times. Yet, the tediousness of reasoning about the properties of specifications evident in [20] shows there may be much room for improvement in this area. Amongst other, the use of an FMs tool should not be harder than that of the FM itself. Smart 4IR technologies should assist with these tasks.

The research agenda and accompanying validation meet our research objective.

IV. Conclusions and Future Work

This paper presented a high-level research agenda for the management of Formal Methods as a software development methodology using the opportunities of the fourth industrial revolution. Challenges with semi-formal notations were illustrated through an attempt at formalising part of the Quality 4.0 framework. Formal specifications as a starting point of a formal methods methodology bring about challenges of their own. It is argued in this paper that intervention through leadership management or governance coupled with opportunities in the 4IR could promote the use of FMs as a viable software development methodology, leading to the said research agenda in Table 1.

The work presented in this paper forms part of an umbrella project aimed at the commercial acceptance of FMs as a software development methodology. Much has been written and indicated above about the advantages and disadvantages of FMs usage, and the debate is ongoing. The researcher is of the opinion that the challenges around the adoption of FMs should be addressed from multiple angles, all working towards a common goal. One of these, presented in this paper is from the angle of leadership management as a driving force, assisted by the opportunities and promises of the 4IR. A complementary angle embodies a bottom-up approach in which the *low-level* challenges of FMs usage are unpacked through problematisation frameworks [13]. It is anticipated that such problematisation, once fully developed could be embedded as a solution in part of the cross-functional management sector of the Table 1 agenda.

Future work in this area should, therefore, follow the suggestions in the research agenda. The role of leadership management should be investigated in conjunction with a deeper analysis of the specifics of the 4IR promises. Together with these, the adoption of FMs as a technology should be investigated on the strength of the technology acceptance models, leading to possible enhancements of these models.

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