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The Role of 4IR-5IR Leadership-Management in the Adoption of Formal Methods

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Abstract: Formal methods (FMs) have been cited as a viable methodology for developing high-quality software. However, the steep learning curve in efficiently using the underlying discrete mathematics and logic has hindered FMs' adoption, leading to a decline in their initial interest in the 1980s. Traditionally, technical approaches have been pursued to address the FMs challenge. Having taken cognisance of a similar pre-4IR decline in AI, the researcher views FMs as technology and considers solutions at intersections of 4IR-5IR technology adoption, leveraged by the support of governors, termed leadership-management in this work. Following a qualitative research choice, scholarly literature is reviewed, and sets of qualitative propositions are defined to develop a conceptual framework for a 4IR-5IR leadership-management adoption of FMs. Aspects that emerged and are incorporated into the framework are cross-functional and executive levels of leadership, transformative, adaptive, and servant leadership styles, using FM tools that embed a high level of user experience, and 4IR technologies, augmented with 5IR human aspects. The framework is hoped to motivate a company's leadership to contribute to technology and technical ICT-based decision-making increasingly. Future work in this area would involve securing input from practitioners and exercising the framework in an industrial setting.

Keywords: Fifth Industrial Revolution (5IR); formal methods (FMs); formal specification; Fourth–Fifth Industrial Revolution (4IR-5IR); leadership-management; propositions; technology adoption

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1. Introduction

Similar to many industries, the software industry has made great strides in improving its processes and products [1]. Examples of these include improved requirement engineering practices [2]; active learning automata and quality control [3]; textual specification languages [4]; typical generative AI-4IR initiatives such as ChatGPT [5] and Grammarly [6] for generating and correcting document content; device communication [7]; and several other developments. Many of the recent software developments are arguably linked to environmental concerns, e.g., Green Computing, in line with the United Nations SDGs [8].

Despite the software industry's advances in the aforementioned areas, challenges remain. Projects continue to run over budget, are late, or are never completed [9]. Several of the above developments rely on natural-language platforms or semi-formal notations, such as diagrams. Yet, given the challenges of ambiguity with semi-formal software development methodologies [10], formal methods (FMs) as a so-called "silver bullet" for software challenges have been proposed and cited as a desirable activity for constructing correct software that meets its specification.

Various formal notations and approaches have been developed. Earlier techniques include automata theory [3] for systems modelling; abstract and formal specification notations, e.g., Z [11]; and formal reasoning about a system's properties [12], activities often based on mathematical set theory and logic [13]. In this work, the researcher views FMs as the processes involved in formally specifying a system, reasoning about the specification's properties, and transforming (refining) the specification into code [14] that can be compiled and executed on a real machine.

However, the use of formality for systems development has not been met without controversy. Advocates of the use of FMs point to the advantages to be gained in proving the correctness of the resultant system, especially in the case of mission-critical software development [15]. Critics of FMs point to the steep learning curve in becoming proficient in the underlying discrete mathematics and logic [16]. In this regard, the traditional starting point in FMs usage is constructing a formal specification, after which a specifier may reason about the properties of the specification, showing that it meets the intentions of the clients and the specifier and that adverse results will not result from a true implementation of the specification [14,17]. While the use of FMs may be most prominent for mission-critical applications, e.g., nuclear power applications and commercial software, an enterprise resource planning (ERP) system may likewise be considered mission-critical and should, therefore, be equally correct [18]. However, FMs acceptance in the commercial world, driven by financial factors, is likewise slow [19].

FMs held great promise in the 1980s [20], yet their hype broke off owing to the difficulties involved in their efficient use. Remarkably, Artificial Intelligence (AI) followed a similar route, given humanity's vast interest in AI in the late 1900s. Yet, AI is very much back on the scene, and it happened primarily because the Fourth Industrial Revolution (4IR) introduced technologies that made AI a viable technology that was not possible before. The researcher believes FMs acceptance could follow a similar trajectory, facilitated by 4IR technologies and ongoing human intervention in the face of the 5IR. As was the case with AI, the hype of FMs broke off, and FMs' usage has since moved into a trough of disillusionment (evident in most Gartner® Hype™ cycles). The researcher believes that, amongst others, the efficient use of 4IR technologies could present a future avenue for sustainable FM usage.

Viewing FMs as a technology that 4IR technologies could advance gives developers access to various technology adoption frameworks or models. Various technology adoption frameworks or models are utilised in the industry. Examples constitute the well-known Technology Acceptance Model (TAM) and the later Unified Theory of Acceptance and Use of Technology (UTAUT) [21] or the Technology Organization Environment (TOE) [22]. The TOE and enhanced versions thereof may be most suited for our work, as discussed further in Section 3. Naturally, accepting a specific technology is only the first step. The real test comes with how sustainable the technology's long-term use is. In this regard, we believe Chihande's [23] work in post-adoption success may be key to the long-term sustainability of FMs use.

Numerous 4IR frameworks have been developed over time, embodying various levels of detail, resulting in possible ambiguity. A prominent example is the Quality 4.0 framework, which we evaluate in Section 3.2.1 for its suitability for formalisation. Another important framework in the context of this work is Leadership 4.0, which was developed by Kwiotkowska et al. [24] from Industry 3.0 concepts. Leadership 4.0 is discussed in Section 3.3.

Coupled with 4IR technologies, a company's management may further leverage the use of FMs since middle management, such as chief information officers (CIOs) or chief digital officers (CDOs), may buy into FMs usage and promote it in their respective companies. Further leverage could be achieved through the support of a company's leadership in the form of upper management, e.g., the chief executive officer (CEO), or governance structures of a company [25]. In this article, the combined governance efforts of middle and upper management are called leadership-management (L-M). Apart from the work by the researcher [25], the literature on the important role to be played by management in the adoption of FMs is sparse. A seminal 2003 publication by Stidolph and Whitehead [26] laid down some ground rules for managers to promote FMs for systems development, elaborated in Section 3.6.

The literature on contemporary perspectives of FMs in the context of the 4IR-5IR is equally sparse. To the best of my knowledge, the researcher's work presents the only developments in these areas. Consequently, this article builds on my previous work in that a preliminary problematisation framework for 4IR-5IR adoption of FMs appears in [27], and a research agenda for the role of FMs governance was published in [25]. The current work extends previous work in two aspects, namely, employing the theory of qualitative propositions developed by the researcher in [28] to enhance the FMs-4IR-5IR adoption through the perspective and influence of governors, coined leadership-management in this article, representing the unique contribution of this work.

The layout of the rest of the article is as follows: following the above introduction, the research questions and objective of the article are formulated in Section Research Questions and Objective. The methodology underlying this work is presented in Section 2, followed by the results presented in a literature review on FMs, 4IR-5IR interplay, technology adoption with an emphasis on FMs as a technology, and leadership-management in Section 3. The framework that represents the deliverable of this work is presented in Section 3, followed in Section 4 by a discussion of its content as synthesised in this article. Previous and related approaches to addressing the FMs adoption problem are given in Section 5. Conclusions and directions for future work in this area are presented in Section 6, followed by a list of references.

Research Questions and Objective

The research aims to find an answer to the following questions:

RQ1: What are the advantages and disadvantages of formality for systems development?

RQ2: What mechanisms may assist in adopting FMs as a technology?

RQ3: How may leadership-management facilitate the adoption of FMs?

The objective is the following:

Develop a 4IR-5IR leadership-management framework for the adoption of FMs.

2. Materials and Methods

The research in this article is conceptual, and our research methodology is based on the generic Research Onion proposed by Saunders et al. [29], depicted in Figure 1. In developing our methodology through the layers, we present our research design, data collection through scholarly literature, analyses of the collected data, and theoretical aspects related to framework construction and qualitative propositions.

Following the onion from the outer layer, our research philosophy in this work is a blend between interpretivism and positivism. Our philosophical selections ought to be viewed considering the design choices of reviewing scholarly literature to identify the role of leadership-management (L-M) in the 4IR-5IR. As indicated in Section 3 results, the survey starts with reviewing leadership in the 4IR, as well as FMs in the 4IR. As indicated in the following sections, the literature on FMs in the 4IR is sparse. The idea of viewing FMs as a technology is also considered, but again, the literature is rather silent on it. The researcher would also review the literature on leadership-management in the 4IR and, more specifically, L-M in the 4IR-5IR. Our interpretivist stance stems from the fact that most of the 4IR frameworks are depicted as diagrams, i.e., semi-formal notations [30] that may exhibit ambiguity (cf., the Quality 4.0 framework discussed later). Our philosophy also has a positivist character since the FMs notations in the form of formal specifications embed discrete mathematics and logic, as is evident throughout Section 3.

Moving to the next layer, the approach to theory development is inductive since a qualitative framework for sustainable FMs adoption is developed on the strength of the literature. Framework development, which may be considered a forerunner of model building through quantitative, statistical analyses, serves as part of the theoretical underpinning of this work. Framework development in this article rests on the theory of qualitative propositions, as developed by the researcher in earlier work [28]. Propositions are defined through analyses of literature text and diagrams. The resultant framework may be viewed as an instantiation of a problematisation framework in that we question the traditional [31] technical approaches to FMs adoption. Following the inductive framework development phase, our approach is also deductive in that the framework developed is briefly validated theoretically. Therefore, our work is conceptual at this point, and, as indicated in the future work part of this article, follow-up research will involve surveys among leaders and FMs practitioners in relevant industries.

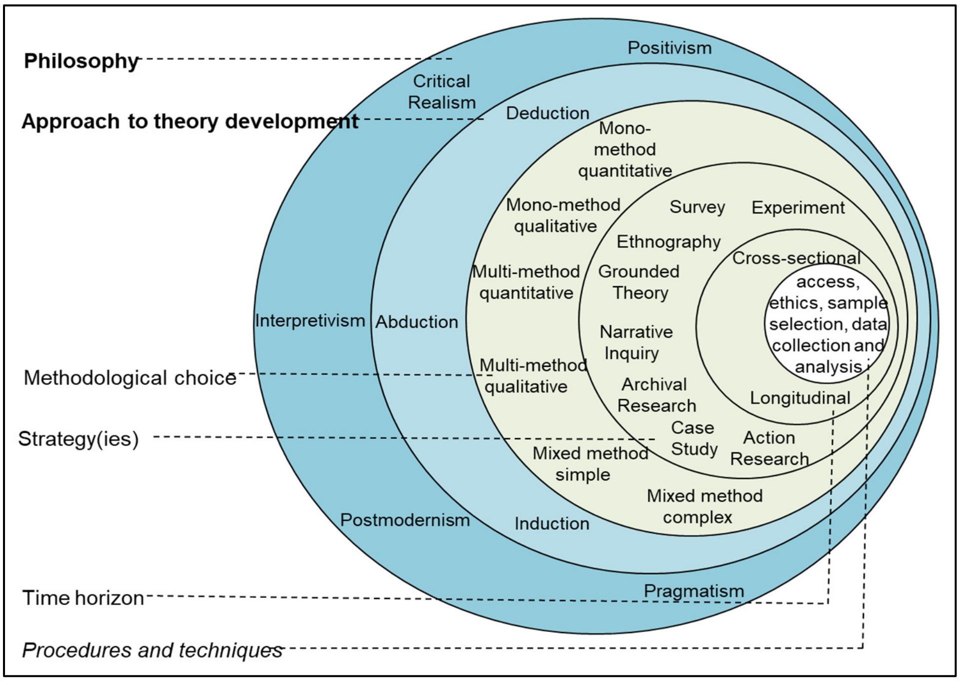

Figure 1. Saunders et al. (2024) Research Onion [29].

Our methodological choice at the third level from the outside is mono-qualitative, augmented with a pseudo-quantitative choice. Our choice is qualitative since the researcher's actions at this layer would be a mix of inspecting semi-formal diagrams and analyses of formal specifications based on set theory and logic, thereby adding a pseudo-quantitative research choice to this work. Amongst other actions, an attempt is made at formalising a prominent 4IR framework, namely, Quality 4.0, in Section 3.2.1. Other 4IR frameworks in this article could likewise be formalised, but to balance the methodological choice, the researcher decided to follow a qualitative inspection of the other 4IR frameworks. We note that a quantitative choice usually involves statistical analyses, hence the pseudo-quantitative denotation of our work.

In the fourth layer of the onion, this work's research strategy is case study-based since the various 4IR frameworks in this article will be viewed as cases of the 4IR and, in some instances, 5IR enhancements. Since this research is performed over a shorter period, the time horizon at level five is cross-sectional. That said, we note that should our work garner traction in the relevant industries, then it would embody a longitudinal time horizon, whereby the ideas would be tested as cases in the said industries, possibly over several years, as we move into the 5IR and beyond.

Finally, at the innermost layer of the onion, the data collection and procedures involve reviewing scholarly literature characterised by textual descriptions and semi-formal 4IR structures discussed in the context of the third layer of the onion. The procedures embody analysing these structures through the inspection of their content. Therefore, the data collection in this article has a qualitative flavour.

Next, we discuss the use of the qualitative propositions mentioned above.

2.1. The Use of Qualitative Propositions

As indicated above, the 4IR-5IR-L-M framework developed in this work is synthesised from the qualitative propositions developed from the literature review in Section 3. A proposition in our context states the attributes of the building blocks of a framework or denotes an association among two or more entities or characteristics in the framework. Consequently, our propositions in this article are of two kinds [28]:

- *Content* propositions indicated by pCi for $i \in \{1, 2, 3, \ldots\}$. A content proposition indicates attributes of building blocks of a framework and is looked upon as the attributes or descriptions of the contents of an entity in the framework.
- *Association* propositions indicated by pAj, $j \in \{1, 2, 3, \ldots\}$. An association proposition indicates an association among two or more entities in the framework and is reminiscent of hypotheses in quantitative work but viewed qualitatively.

Intermediate versions may result during proposition development. A lowercase alphabetic character suffixed to a proposition's integer (number) denotes an intermediate version. The alphabetic character is dropped once the proposition emerges in its final form. This article gives examples of intermediate and final versions of propositions.

2.2. Ethical Clearance

The research reported on in this article received ethical clearance from the home faculty and university of the researcher under ethical clearance number Ref #: 2023_SBL_AC_010_EX_1163.

3. Results

As presented by our methodology, the results embody a review of scholarly literature, followed by a conceptual framework for sustainable FMs acceptance through 4IR-5IR technologies and the leverage of Leadership-Management.

Tracing a company's digital transformation towards reliable system development, we start with considering the value proposition of FMs by investigating ambiguities in a semi-formal (diagrammatic) notation, reasoning about the properties of a specification, transformation to a running system and challenges related to formal specification. The discussion then turns to technology adoption and leadership styles that may contribute to the researcher's idea of 4IR-5IR leadership-management, culminating in a conceptual framework in Section 3.7.

3.1. Formal Methods

Advocates of FMs for system development point to their advantages in producing the correct software, especially mission-critical applications where human life or human well-being may be at stake [32,33]. Yet, there are difficulties in learning the underlying discrete mathematics and logic to develop a formal specification proficiently, which is usually the front-end of an FMs approach [34].

Contributors at a recent workshop on the scalability of FMs [35] questioned the need for expert knowledge of discrete mathematics and logic to use FMs. The viewpoint put across is that the growing diversity of models and methods allows for the incremental adoption of FMs, and hybrid systems of semi-formal and formal specifications are possible. While the researcher, in principle, agrees with these views, we show in Section 3.3 how an incremental specification approach leads to inconsistency. The challenge with hybrid systems may be similar to the data warehouse problem of maintaining both structured and unstructured data [36], compromising system performance. Hybrid systems may also lead to the familiar challenge of modern parts of a system being interleaved with legacy systems.

Tool support is a much-needed development for FMs adoption, yet the user experience of these tools may be troublesome [12] in the case of Event-B/Rodin for reasoning about set theoretic specifications. These tools may also be slow for industrial-sized systems. Nevertheless, ref. [35] reasons that modern FM tools exhibit improved performance, but in the researcher's experience, several companies, especially those in developing economies, run systems on poor and dated infrastructure, thereby compromising FM tool performance. Poor performance of tools supports the viewpoint that some FMs implementations are sold to industry while still immature [34].

Despite the slow adoption of FMs in the commercial world, there is an increasing "pull" by practitioners in complex business-critical applications to use FMs, in contrast to the "push" for FMs by researchers [35]. The practitioner pull effect supports the spirit of this research, namely, FMs adoption through 4IR-5IR leadership-management.

Returning to the need for proficiency in discrete mathematics and logic to apply an FM leads to a preliminary version of our first content proposition:

- *Proposition pC1a*: The efficient use of FMs for system development necessitates the training of developers in discrete mathematics and logic to produce a formal specification.

We also arrive at the following association proposition:

- *Proposition pA1*: raining offered to employees may be technical for developers or managerial for upper management.

Formal specification notations may broadly be divided into algebraic-, process algebra-, and model-based approaches. Following an algebraic approach, a system is specified as a set of axioms of which the properties are to hold throughout the lifetime of the system, as it moves through various operations. A prominent example of the algebraic approach is OBJ [37]. As the name indicates, a process algebra approach specifies a system more procedurally and is, amongst others, useful for multiprocessing. CSP is a popular specification language in this group [38]. Model-based approaches specify a system as moving from state to state, defining operations on each state, accompanied by appropriate pre- and postconditions for operations. One of the prominent specification languages in this group is Z [11], based on a strongly typed fragment of Zermelo–Fraenkel set theory and first-order logic. Other examples include B, which constitutes an entire development environment, in addition to formal specification [12]. Owing to its expressiveness and relative simplicity, the researcher favours the Z specification language with formal semantics [39]; hence, it is used in this article to illustrate FMs' concepts.

The discussion of specification notations leads to preliminary versions of a content proposition and an association proposition:

- *Proposition pC2a*: o facilitate the training of developers, a formal specification language selected from algebraic, process-based, and model-based approaches should exhibit relative simplicity, yet be expressive.
- *Proposition pA2a*: formal specification is associated with choices among one or more specification styles.

Despite the advances made by the 4IR, we show in Section 3.2.1 that a formal method can elicit ambiguities in 4IR structures. FMs, however, are not without their problems; we show in Section 3.3 one of the dark corners of a formal specification.

3.2. Fourth-Fifth Industrial Revolution (4IR-5IR)

It is generally accepted that the fourth industrial revolution started in 2012 [40,41], and like past industrial revolutions, the initial developments were technical; in the case of the 4IR, it embodies Industry 4.0 technologies. Among the prominent technologies are the (Industrial) Internet of Things ((I)IoT), Augmented Reality (AR), Cloud/Edge Computing (C/EC), Printing 4.0 (3D printing), blockchain, and Artificial Intelligence (AI) [42] to name but a few. While the researcher values all these technologies to promote the use of FMs for correct systems development, AI would, arguably, be the main driver since sustainable (post) adoption of FMs could piggyback on how the 4IR reinvigorated AI from the trough of disillusionment it was in before.

The above discussions lead to the following:

- *Proposition pC3*: prominent 4IR technologies include, amongst others, the IIoT, AR, C/EC, Printing 4.0, blockchain, and (generative) AI, of which AI may be the most prominent in guiding the path for FMs usage as a technology.

An association proposition regarding humans and 4IR technologies also emerges, but we shall defer its definition till later (refer to Section 3.4).

A Gartner–Hype™ cycle may be a useful framework to describe and predict technological developments. In this regard, Figure 2 illustrates the growth and expectations of various instantiations and applications of AI, e.g., generative AI (GAI), and AI-augmented software engineering.

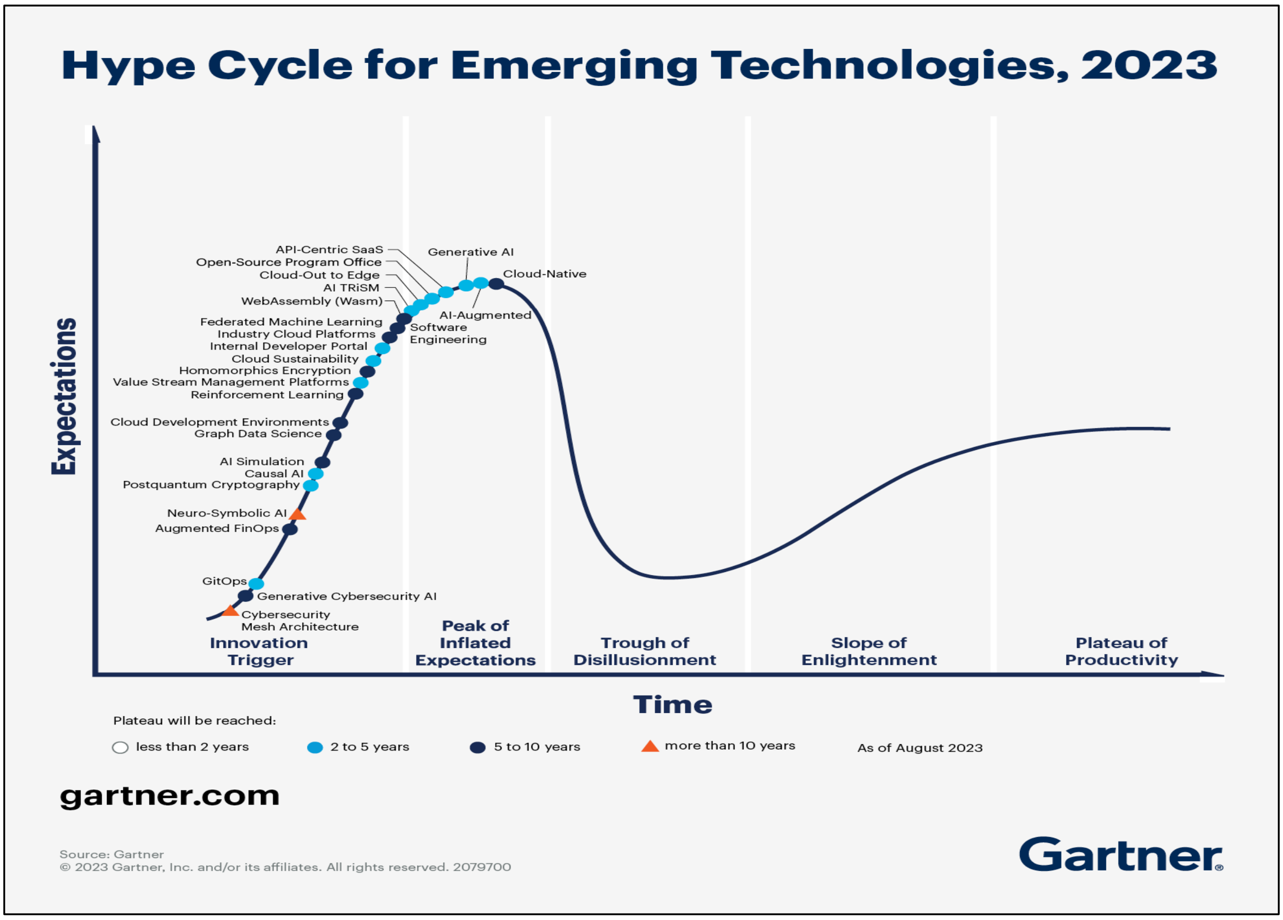

Figure 2. Gartner–Hype™ cycle for modern technologies (source: https://www.datanami.com/2023/08/24/genai-debuts-atop-gartners-2023-hype-cycle/) (accessed on 12 August 2024).

The effective use of FMs could result in AI-augmented software engineering in Figure 2, but software developers using traditional methodologies may not view it this way. Nevertheless, piggybacking on AI as part of 4IR technologies could, in the light of Figure 2, predict future cycles in FMs' adoption and post-adoption use [23].

Consequently, we arrive at the following proposition:

- *Proposition pC4*: a Gartner–Hype™ cycle could be used to predict the industry's uptake of FMs. Coupled with this would be predictions on the post-adoption use of FMs, i.e., the sustainable use of FMs.

Numerous 4IR frameworks have been developed to account for adopting 4IR technologies in various applications. Two prominent frameworks, namely, Quality 4.0 (Q4.0) and Leadership 4.0 (L4.0), are presented in the following sections, and we use a formal method to elicit possible ambiguities in at least one of these frameworks.

Turning to the 5IR, we note that this revolution is not a technical revolution; rather it is about bringing the human back into 4IR technologies. Aspects considered in the 5IR are the harmonious collaboration between humans and machines [43] and the ethics of robots, as they work side by side with humans, either as peers or leaders in the industry. We return to this point in Section 3.6 in the context of leadership-management.

3.2.1. Quality 4.0

The quality of a system is linked to its dependability and correctness; hence, a system of high quality exhibits these features. The Q4.0 framework was developed to enhance traditional quality (cf. Quality 3.0) into the 4IR. The Q4.0 framework is shown in Figure 3.

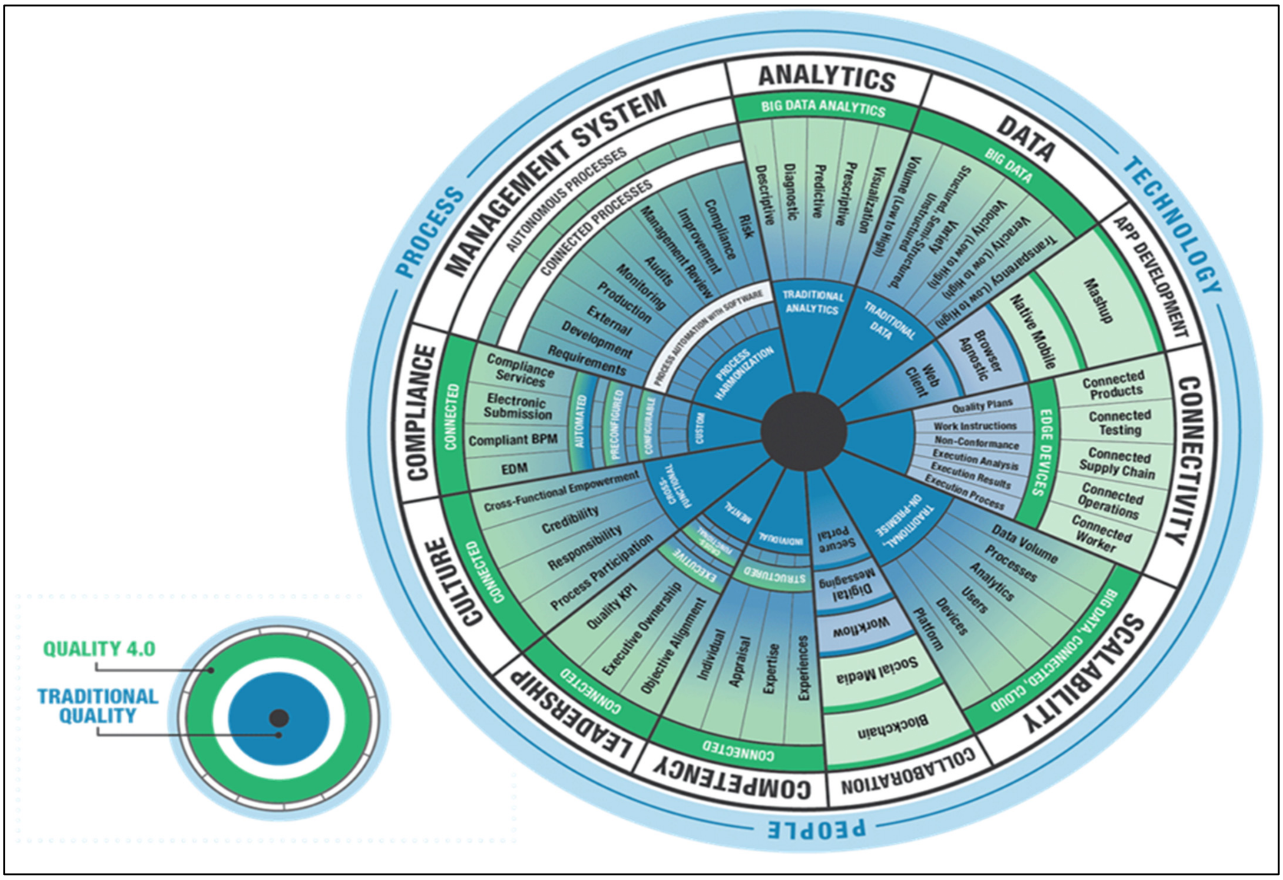

Figure 3. Quality 4.0 framework (source: https://www.juran.com/blog/quality-4-0-the-future-of-quality/) (accessed on 12 August 2024).

The Q4.0 framework includes traditional quality (Q3.0) at its core and defines three concepts: process, technology, and people at its outer rim. Including humans (cf. people) at the outer level is significant, since it fits with the 5IR principles of bringing humans back into the 4IR.

The following proposition underwrites the significance of including humans in a 4IR structure:

- *Proposition pC5*: in moving from the 4IR to the 5R, humans should play a central role in the 4IR-5IR structures.
    - ❖ Regarding robots as leaders, their ethical behaviour is paramount.

Returning to the Figure 3 framework, the next layer from the outside comprises 11 concepts, including leadership, which is further analysed below.

The leadership group links with connectedness, i.e., an apparent 1-1 association, indicated by a bijection, and therefore incurs an ambiguity regarding the framework.

Ambiguity 1.

$$LEADERSHIP \twoheadrightarrow CONNECTED$$

The ambiguity results from the uncertainty of whether the association is 1-1 or something else. *Connected*, in turn, associates with three concepts. Yet, the framework does not indicate whether there is an ordering among the three concepts.

If an order is intended, then it may be defined by a Cartesian product:

$$CONNECTED \mathrel{\widehat{=}} Objective\_Alignment \times Executive\_Ownership \times Quality\_KPI$$

However, if no order is intended, we may define *connected* as a Z schema, where the concepts denote three components, assuming the basic types [*ALIGNMENT*, *OWNERSHIP*, *QUALITY*].

CONNECTED
Objective_Alignment : ALIGNMENT
Executive_Ownership : OWNERSHIP
Quality_KPI : QUALITY

Either way, the orderedness or lack thereof of the components gives rise to uncertainty, which we may indicate as Ambiguity 2.

Ambiguity 2.

Component *CONNECTED* in Figure 3 may be defined lower down as a Cartesian product or unordered Z components.

Following the development of each of the three components in the schema, *connected* reveals further ambiguity. Again, assuming an order, the three-tiered components map to *EXECUTIVE* as follows:

Definition 1.

$$ALIGNMENT \times OWNERSHIP \times QUALITY \nrightarrow EXECUTIVE$$

Definition 1 specifies a partial mapping ($\nrightarrow$). Hence, not all three concepts are needed to define *executive*. If not, then a bijective definition should be used, i.e., we replace "$\nrightarrow$" with "$\rightarrowtail\!\!\!\!\twoheadrightarrow$" in Definition 1. This decision gives rise to Ambiguity 3.

Ambiguity 3.

Component *EXECUTIVE* in Figure 3 may be partially defined by the components in Definition 1. Otherwise, it is wholly defined by the components, giving rise to a bijective definition.

If no order among the three components is intended, we may have the following, also serving as Ambiguity 4.

Ambiguity 4.

$$ALIGNMENT \nrightarrow EXECUTIVE$$

$$OWNERSHIP \nrightarrow EXECUTIVE$$

$$QUALITY \nrightarrow EXECUTIVE$$

As before, an ambiguity regarding partial or bijective mappings remains.

Taking our definitions regarding Figure 3 one level deeper, we note that three further and unnamed components are associated with *EXECUTIVE*. Presumably, these would be defined in specific applications of the Quality 4.0 framework, but generically, for the case at hand, these could be defined by (assuming *UNKNOWN* is defined as a basic type in Z):

$$\begin{array}{|l}\hline \textit{EXECUTIVE} \\ \textit{Un\_named\_1, Un\_named\_2, Un\_named\_3 : UNKNOWN} \\ \hline\end{array}$$

Each of the three unknown components in the above schema maps further down in Figure 3 to cross-functional leadership, as follows (*CROSS_FUNCTIONAL* a basic type):

Definition 2.

$$(\forall \mathrm{i} : [1 \,..\, 3])\ (\exists\ \textit{cross\_functional} : \textit{CROSS\_FUNCTIONAL}) \bullet$$

$$\textit{Un\_named\_i} \mapsto \textit{cross\_functional}$$

Definition 2 assumes that each of the unnamed components in Figure 3, cf. schema *EXECUTIVE* above, maps to an instance of cross-functional leadership, giving rise to Ambiguity 5. The rest of the leadership sector towards the core (*MENTAL* component) may be analysed similarly.

We arrive at the following proposition:

- *Proposition pC6a*: having observed leadership in a prominent 4IR structure, management's support of FMs may be at the executive or cross-functional level.

The above development illustrated several ambiguities in a prominent 4IR framework. These ambiguities are elicited through formalising a semi-formal structure, thereby illustrating the value proposition of mathematical formality. The researcher acknowledges that the Quality 4.0 framework is generic and was not designed to be rigorously formalised as we did above.

The following proposition emerges:

- *Proposition pC7*: modern 4IR frameworks, depicted as semi-structured diagrams, may still exhibit ambiguity that could be addressed through FMs.

We return to aspects of executive leadership and functional leadership as captured in the Quality 4.0 framework in the discussion on leadership-management in Section 3.6.

The challenges observed with a semi-formal 4IR structure partly answer our first research question, **RQ1**.

3.2.2. FMs in the 4IR

Apart from the researcher's work [27], the literature is relatively silent on embedding FMs in the 4IR and extended by the 5IR. Recent work on FMs concentrates on teaching FMs in either a face-to-face or online environment [44] while [45] addressing teaching in the 4IR but not FMs-related. The teaching of FMs as part of a computer science curriculum using tool support, discussed in [46], is likewise devoid of 4IR considerations or 5IR considerations; the 4IR is assumed to be embedded implicitly. That said, the researcher believes FMs deserve special consideration, especially if these are to be viewed as a technology eventually on par with AI in the 4IR. Tracing the recent path of generative AI (cf. Figure 2) may well predict the future adoption of FMs, leveraged by leadership-management, discussed in Section 3.6.

These observations enhance an earlier proposition:

- *Proposition pC1b*: The efficient use of FMs for system development necessitates the following:
  - ❖ Developers should be trained in discrete mathematics and logic to produce a formal specification.
  - ❖ Software tool usage should be included in FM courses.
  - ❖ Attention should be paid to the role of the 4IR in promoting FMs.

3.2.3. Towards the 5IR

Given the emphasis of the 5IR on harmonious collaboration between humans and machines and the ethics of robots, one could augment Quality 4.0 or, plausibly, any 4IR framework with 5IR concepts. Since harmonious collaboration and ethics are high-level concepts, these could be built into (or added to) the outer rim of Figure 3, for example, as subcategories of *people*. These observations support proposition *pC5* above.

Tool support has been cited to facilitate the use of FMs (cf. proposition *pC1b*), but the tool itself may be as difficult to use as the FM itself [12]. Therefore, user interfaces supporting a high level of user experience of FMs tools are paramount. In this regard, 5IR initiatives of harmonious collaboration between humans and machines (cf. software tools) facilitate FM tool support, enhancing an earlier proposition:

- *Proposition pC1c*: the efficient use of FMs for system development necessitates the following:
  - ❖ Developers should be trained in discrete mathematics and logic to produce a formal specification.
  - ❖ Software tools supporting a high level of user experience to leapfrog into the 5IR should be included in FM courses.
  - ❖ Attention should be paid to the role of the 4IR in promoting FMs.

3.3. Leadership Perspectives

The leadership sector in Quality 4.0 specifies two levels of leadership: executive leadership and cross-functional leadership. In this work, we consider both levels aimed at a comprehensive treatment of FMs adoption. Simonet and Tett [47] discuss the differences and similarities between management and leadership. Having surveyed 43 experts, they concur that hierarchically, there is management within leadership and leadership within management. Hence, these two concepts overlap intricately.

Within each leadership level, leadership styles vary greatly; amongst others, a transactional style, whereby a leader awards subordinates for their cooperation or good work delivered but penalises group members should they not be up to standard. An autocratic/authoritarian style links with a transactional style in that leaders have complete control over their subordinates, who have little say in decisions, and neither put their ideas into practice [48]. Transactional or autocratic leadership styles lead to efficiency in decision-making but may lead to unhappy group members. A democratic or participative style, on the other hand, considers group members' opinions and suggestions to move forward collectively [48,49].

A participative leadership style is also linked with an adaptive approach, in which synchronicity between the leader and group members is established; hence, group members participate in decision-making [49]. Adaptive leadership assumes that leadership is more of a process, e.g., the process of adopting technology; changes may be made for the greater good of the institution. In a servant leadership style, leaders serve their subordinates. A transformational leader seeks to transform a system or the status quo [50], e.g., adopting FMs as a software methodology. Servant leadership leads to a richer level of employee innovation than transformational leadership [51].

The above observations, together with the Quality 4.0 framework, lead to the following:

- *Proposition pC6b*: having observed leadership in a prominent 4IR structure, management's support of FMs may be at the executive or cross-functional level to facilitate FMs adoption:
  - ❖ A transformational style with elements of consultative, participative, and adaptive styles may be preferred.
  - ❖ To facilitate the buy-in of team members, a servant leadership style should be preferred over an autocratic style.

Next, we consider leadership in the 4IR context and discuss a Leadership 4.0 framework.

Leadership in the 4IR

Reference [52] established a three-way association among Leadership 4.0, creative management methods, and organisational performance capabilities. Enthusiasm was further identified as an important Leadership 4.0 dimension. During the COVID-19 pandemic, leaders had to resort to leading digitally instead of face-to-face [53]. Consequently, increased digitalisation through 4IR technologies greatly facilitated digital leadership (DL). The researcher notes that DL during the pandemic maps onto the CODeL of FMs [54], which academics, likewise, had to resort to.

Various leadership frameworks have been defined to guide the industry to utilise the opportunities of the 4IR. Roux [55] expanded Day et al.'s 2009 model [56] for integrated leadership to account for growth in leadership mindset, curiosity, and learning agility. The researcher believes these ideas fit well with the characteristics that the 4IR aims to instil in the robotic leadership of the future. Consequently, we arrive at the following:

- *Proposition pC8a*: 4IR-5IR leaders should embody the leadership aspects of curiosity, learning agility, and a general leadership mindset.

We note that proposition *pC8a* supports our preliminary proposition *pC6b*.

Figure 4 depicts a Leadership 4.0 framework developed by Kwiotkowska et al. [24], in which our proposition *pC6b* combines leadership styles and simultaneously incorporates knowledge acquisition, creation, and innovation in Industry 4.0.

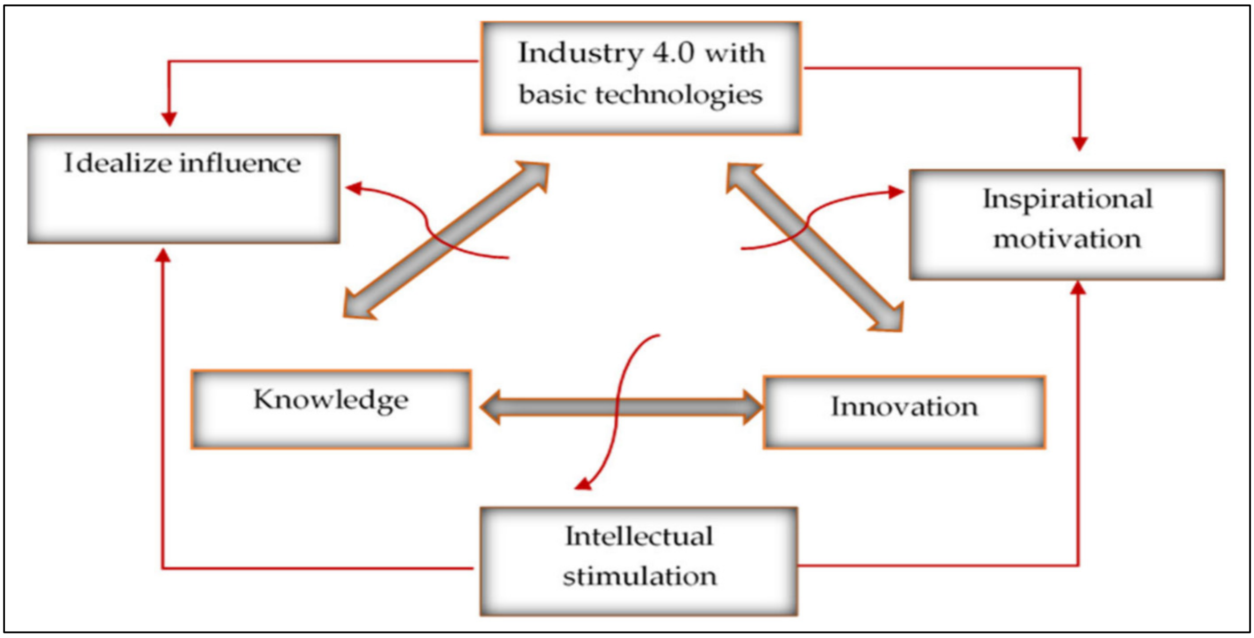

Figure 4. Leadership framework incorporating 4IR considerations (source: Kwiotkowska et al. [24]).

Naturally, the Figure 4 framework does not explicitly mention "leadership" but instead focuses on the building blocks or aspects involved in leadership. In addition to incorporating Industry 4.0 technologies, aspects of inspiration, influence, stimulation, and knowledge (acquisition and creation) are key to the Figure 4 framework. Innovation, regarding both technical (4IR) aspects and commercialisation in moving from a scientific or engineering invention to a commercial product (e.g., new product development [57]), is a further key component of the framework. Possible additions to the Figure 4 framework could be enthusiasm, as identified by [52], but it could be an element of, for example, the inspirational motivation entity in an expanded version of the framework. Leadership styles could also be embedded in one or more entities of the framework. Given the complexities and uncertainties of the 4IR for employees, aspects of adaptive, consultative, and servant leadership could be included, but all these could likewise be implicit in inspirational motivation.

Munsamy [58] defined a framework for assessing leadership competencies in the 4IR. Organisational culture and adaptability, amongst other components, form important components of the framework. This points to the need for adaptable leadership while maintaining the well-being of employees, as indicated earlier. Such a competency framework may pave the way towards maturity models for 4IR frameworks [59].

We note that the above discussions support our preliminary proposition *pC6b*.

As indicated before, the researcher contends that the 4IR to 5IR transition will introduce robots that will take up leadership positions in the workplace. These machines must exhibit ethical behaviour and contribute to harmonious collaboration with humans [27].

The framework presented in Figure 4, in conjunction with the above discussion, enhances proposition *pC8a* in its final form as follows:

- *Proposition pC8*: 4IR-5IR leaders, either robots or humans, should embody the leadership aspects of curiosity, learning agility, and a general leadership mindset. In addition to a conducive leadership mindset, 4IR-5IR leaders should perform the following:
    - ❖ Exert influence and inspire subordinates and peers.
    - ❖ Possess a learning agility linked to curiosity.
    - ❖ Stimulate the acquisition and creation of knowledge.
    - ❖ Be innovative, both regarding technical (4IR) aspects and commercialisation.
    - ❖ Underwrite ethical behaviour towards colleagues, human or otherwise.
    - ❖ Maintain transactional leadership and move towards transformational leadership, embedding the consultative, participative, adaptive, and servant leadership styles.

We note that proposition *pC8* supports preliminary proposition *pC6b* regarding leadership styles for FMs adoption.

From the competency framework in [58], we conclude the following:

- *Proposition pC9*: maturity models for Leadership 4.0 frameworks ought to be enhanced for the 5IR and collectively adopted as part of 4IR-5IR FMs.

Throughout the above discussions, we note that the 4IR leadership literature does not address the adoption and subsequent use of FMs in the 4IR.

Next, we illustrate that formality, as suggested by the Z specification language, is not without challenges.

3.4. Pitfalls of Formal Specification

Consider a simple application of a voter registration system. The basic types and state space of the system could be the following:

$$[VOTER, BALLOT]$$

Voting_System

$voters : VOTER$

$ballots : VOTER \nrightarrow BALLOT$

$voters \subseteq \mathrm{dom}\ ballots$

Component *voters* denotes all the voters in the constituency at a given time, while *ballots* specify the votes cast by voters.

A voter may register in a constituency to cast a vote at a later stage.

Register

$\Delta\ Voting\_System$

$v? : VOTER$

$v? \notin voters$

$voters' = voters \cup \{ v? \}$

$ballots' = ballots$

The set of voters is updated accordingly, and since a vote has not been cast, the ballots remain invariant (*ballots′* = *ballots*). An after-state variable is specified in Z by a prime (′).

On election day, the voter casts a vote.

$$\begin{array}{|l}
\textit{Cast_Vote} \\
\hline
\Delta\ \textit{Voting_System} \\
v? : \textit{VOTER} \\
\textit{ballot}? : \textit{BALLOT} \\
\hline
v? \in \textit{voters} \\
\textit{voters}' = \textit{voters} \\
\textit{ballots}' = \textit{ballots} \oplus \{v? \mapsto \textit{ballot}?\} \\
\hline
\end{array}$$

The set *voters* remains invariant, while component *ballots* is updated accordingly using the overriding operator (⊕). As an aside issue, we note that owing to the overriding operator, only the last vote will be registered if a voter manages to vote multiple times.

Suppose the system allows an unregistered voter to turn up at the voting station, register accordingly, and proceed to cast a vote. Such sequence may be specified using Z's schema calculus:

$$\textit{Register\_and\_Vote} \mathrel{\widehat{=}} \textit{Register} \wedge \textit{Cast}\_\text{Vote}$$

In expanded form, we have the following:

$$\begin{array}{|l}
\textit{Register_and_Vote} \\
\hline
\Delta\ \textit{Voting_System} \\
v? : \textit{VOTER} \\
\textit{ballot? : BALLOT} \\
\hline
v? \notin \textit{voters} \wedge v? \in \textit{voters} \\
(\textit{voters}' = \textit{voters} \cup \{\ v?\}) \wedge \textit{voters}' = \textit{voters} \\
\textit{ballots}' = \textit{ballots} \wedge (\textit{ballots}' = \textit{ballots} \oplus \{v? \mapsto \textit{ballot}?\}) \\
\hline
\end{array}$$

Schema *Register_and_Vote* displays inconsistent behaviour, illustrating that care should be exercised in applying an FM. On the one hand, FMs may reveal ambiguities in semi-formal structures, e.g., Quality 4.0 mentioned above, while it may incur challenges of their own, leading to our next content proposition:

- *Proposition pC10*: FMs may elicit ambiguities in semi-formal 4IR structures, yet they may incur other challenges, such as combining definitions and operations.

Having identified the above challenges of FMs, we answered our first research question, **RQ1**.

3.5. Technology Adoption

Returning to how AI, as a technology, was revived through the 4IR, we note that FMs could, likewise, be considered a technology that could be advanced by the 4IR and leadership-management, as indicated before. In this regard, considerations of technology adoption as defined by various adoption frameworks and models would be relevant. Some of the prominent adoption models include the Technology Acceptance Model (TAM), the Unified Theory of Acceptance and Use of Technology [21,60], and the Technology Organisation Environment (TOE), with an enhanced version for state-owned enterprises discussed below. Regarding the adoption of FMs, the researcher believes the TOE may be a suitable vehicle for this work, the reason being that TOE integrates the three aspects: technology

(FMs in our case), organisation (ensuring compatibility with a company that is to adopt the technology), and lastly, environment (mapping onto typical software development life cycles (SDLCs) that may include FMs, thereby defining an environment for FM use).

These lead to the following propositions:

- *Proposition pC11*: FMs may be viewed as a technology isomorphic to AI in the 4IR, making available to FM developers the advantages of the 4IR and the various technology adoption models and frameworks.

An association proposition also emerges:

- *Proposition pA3*: governors and management ought to embrace the opportunities and technologies offered by the 4IR and, therefore, FMs as a technology.

The technology adoption models and frameworks have been enhanced since their original introduction; for example, the TOE was enhanced by the researcher's collaborators (Malope et al. [61]), albeit in the context of state-owned enterprises (SOEs). The said enhanced TOE, coined TOE-C, is given in Figure 5.

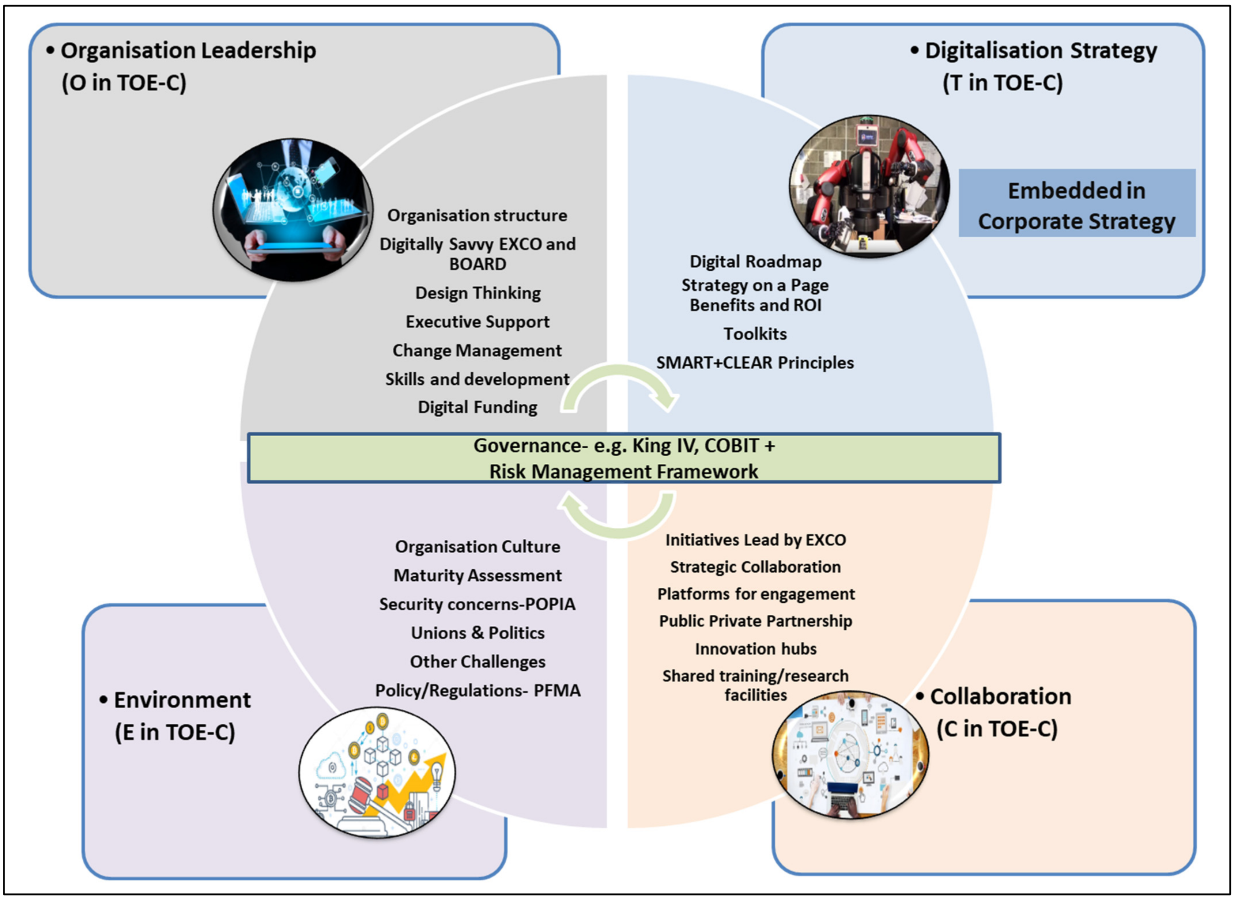

Figure 5. Enhanced TOE framework in an SOE context (source: Malope et al. [61]).

Figure 5 enhanced the standard TOE framework, adding a collaboration component to obtain a Technology–Organization–Environment–Collaboration (TOE-C) framework. While the TOE-C was developed for SOEs in a developing economy [61], we believe it may be an incubator for the FMs' adoption by the industry. The TOE-C includes several aspects introduced in this article, namely, the 4IR in the top right-hand quadrant (digital solutions–AI, blockchain, IoT, etc.); 4IR collaboration in the bottom right-hand quadrant (synergies regarding 4IR development, training, research, etc.), both in support of proposition *pC1*; leadership-management in the top left-hand quadrant (organisation structure, top executives, etc.), in support of proposition *pC15* (which follows later in the context of

Section 3.6, governance discussions); and environment which includes, amongst others, policies, regulations, and environmental challenges (FM challenges in our case). Linking with regulation, standards for FMs' adoption and use should take note of ongoing developments in the Formal Methods Body of Knowledge (FMBoK) [62].

An association regarding technology adoption and 4IR-5IR technologies emerges:

- *Proposition pA4*: 4IR-IR technologies coupled with technology adoption structures inform the use of FMs as a viable 4IR-5IR technology.

Adopting the TOE-C as a framework for facilitating the adoption of FMs in the 4IR leads to the following:

- *Proposition pC12*: FMs' adoption for reliable system development should be guided by underlying policies, legislation, and standards, including the emerging FMBoK and company-specific standards.
    - ❖ The company should furthermore embark on a strategy for FMs adoption.

We also identify the following bi-association:

- *Proposition pA5*: legislation governs using 4IR-5IR technologies and determines the training offered to a company's FM practitioners, management, and governors.

We further note that the TOE-C supports several earlier propositions, e.g., proposition *pC3* regarding 4IR technologies and proposition *pC1* regarding training. TOE-C also supports a governance proposition in the context of leadership-management in Section 3.6 below.

The adoption of FMs ought to be sustainable, viz. [23]:

- *Proposition pC13*: the initial adoption of FMs for reliable system development should support the ongoing, post-adoption use of these techniques in line with sustainable FM use.

We note that proposition *pC13* supports proposition *pC4*.

The above technology adoption discussion answers our second research question, **RQ2**.

Next, we turn to an important component of this article, namely, leadership-management, as synthesised from aspects of management, governance, and leadership, both executive and cross-sectional.

3.6. Governance as Leadership-Management

Apart from the work by the researcher [25], the literature on the important role to be played by management in the adoption of FMs is relatively sparse. Stidolph and Whitehead [26] provide a set of pointers for management to adopt FMs for system development. Synthesised from [26], some of these pointers are as follows:

- Before setting out on FM usage:
    - ❖ Determine the return on investment (ROI). In this regard, FMs' success stories [19], e.g., the IBM CICS successes [35,63], should be studied.
    - ❖ Conduct a thorough risk analysis.
    - ❖ Liaise with early adopters of FMs.
- Employ the services of (1) an FMs expert and (2) one or more consultants.
- Decide which phase(s) of the software development life cycle (SDLC) could be formalised.
- Augment traditional processes with FMs; do not replace all the traditional processes.
- Invest in good support tools for FMs. The support tools should not be harder to use than the FM itself. An example is the tedious use of Even-B/Rodin in discharging proof obligations arising from set-theoretic specifications [12].

The required academic and industry-related qualifications for mission-critical occupations apply likewise to FMs. These should be accompanied by attractive remuneration packages [19].

The above aspects inform two new propositions and enhance two earlier propositions:

- *Proposition pC14*: before adopting FMs, the management and developers should perform the following:
    - ❖ Conduct a thorough risk analysis and determine the return on investment (ROI).
    - ❖ Investigate and study former successes of FMs.
    - ❖ Liaise with early adopters of FMs.
- *Proposition pC1*: the efficient use of FMs for system development necessitates the following:
    - ❖ Developers should be trained in discrete mathematics and logic to produce a formal specification.
    - ❖ Software tool usage should be included in FM courses.
    - ❖ Attention should be paid to the role of the 4IR in promoting FMs.
    - ❖ FMs experts and consultants should form part of the training programme.
    - ❖ Formal academic and industry-related qualifications are required for FMs experts.
    - ❖ Professional status should be available for FMs practitioners, and attractive remuneration packages should be offered.
- *Proposition pC15*: IT governors and company stakeholders should decide which part(s) of the SDLC could be augmented or replaced with FMs. Plausibly, not all traditional processes should be replaced (cf. Stidolph and Whitehead [26] for relevant pointers).
- *Proposition pC2b*: To facilitate the training of FMs developers, a formal specification language selected from algebraic, process-based, and model-based approaches should exhibit relative simplicity yet be expressive. Coupled herewith is the adoption of good support tools to facilitate FMs' development.

A corollary emerging from proposition *pC2b* would be using FM support tools regarding the requirement, specification, and refinement (program transformation), leading to its final version:

- *Proposition pC2*: The following would facilitate the training of FM developers:
    - ❖ A formal specification language selected from algebraic, process-based, and model-based approaches should exhibit relative simplicity, yet be expressive.
    - ❖ Functional support tools for the requirements definition, formal specification, and subsequent transformation (refinement) into a correct system should be adopted.

Propositions *pC14* and *pC15* are new propositions, proposition *pC1* is a final version, and *pC2b* is an enhancement of an earlier proposition, with its final version as proposition *pC2*.

An earlier association proposition is enhanced on the strength of propositions *pC1* and *pC2*.

- *Proposition pA2*: a formal specification is associated with choices among the following:
    - ❖ One or more specification styles.
    - ❖ Tool support regarding automated, interactive, or hybrid reasoning.
    - ❖ Transformation into a correct system.

Building on the Quality 4.0 framework in Figure 3 and the Leadership 4.0 framework in Figure 4, we view leadership in this article as the formulation of common visionary goals for an organisation and then facilitating the buy-in and leading of middle management to realise such goals. Once the said goals have been formulated, the governance structures delegate the implementation of the goals to management, who in turn assemble the various teams to effect implementation. Consequently, strategic thinking, planning, and risk analyses form part of leadership through the governance structures of a company, and the implementation of these decisions is achieved by management and their respective teams [25]. We note that aspects of strategic thinking and risk analyses support earlier propositions, e.g., *pC8* and *pC14*.

Developing high-quality systems may be a visionary goal of the leadership of an organisation through the governance structures, including, amongst others, the company's chief executive officer (CEO). If leadership values the use of formality for correct system development, the management of an organisation would be tasked to find cost-effective ways (cf. proposition *pC14*) of implementing the said vision. In line with the leadership sector of the Quality 4.0 framework above, cross-functional leadership (e.g., middle management) could be guided accordingly by executive leadership (governors) following, amongst others, the Leadership 4.0 skills, and considerations in Figure 4. For example, having bought into the value proposition of FMs for software development, the CEO could motivate employees in the software development unit through the Chief Information/Digital Officer (CI/DO) to adopt FMs as a software development methodology.

Given the intertwined relationship between leadership and governance [64], these two concepts are often used interchangeably to guide management toward implementing the goals set by visionaries, hence our notion of leadership-management. While FM use may lengthen the earlier parts of an SDLC, it can hasten later phases of the cycle, resulting in reduced overall development time [63]. However, owing to initial cost factors (cf. proposition *pC14*) involved in embarking on FMs software development, the support of top management, i.e., the governance structures of a company, would be needed. Consequently, governance and the handing down of decisions to (middle) management is viewed as *leadership-management* in this work, as reflected in the title of this article.

As indicated, ref. [47] advocates that there is leadership in management and management in leadership, c.f., leadership-management in this article. While the literature addresses leadership in the 4IR (refer to Section 3.2.2), the treatment of leadership-management in the extended 4IR-5IR era is largely absent, hence the contribution of this work.

The above observations on IT governance and management structures inform the following:

- *Proposition pC16*: owing to possible risk and ROI considerations, adopting FMs for system development would be a governance, i.e., a leadership-management (L-M) function, rather than an IT management function.

The above L-M presentations answer our third research question, **RQ3**.

As indicated before, leveraging middle management and ICT employees into accepting FMs for their development processes should not equate to an autocratic leadership/governance style. Rather, the value proposition of these techniques should be discussed, and an organisation's leadership-management structures should cultivate a willingness to embark on new processes (cf. proposition *pC15*). Naturally, aspects of employee freedom, the position of one's subordinates, and organisational culture all come into play, calling for a transformational leadership style embedded in consultative, participative, and servant leadership. Furthermore, the training of subordinates (cf. proposition *pC2*), especially the technical personnel, is a vital initiative to be used by decision-makers in adopting FMs for correct systems development.

Recognising employee freedom and organisational culture enhances an earlier proposition into the final form:

- *Proposition pC6*: as supported by a prominent 4IR structure, management's support of FM adoption may be at the executive or cross-functional level:
    - ❖ A transformational style with elements of consultative, participative, and adaptive styles may be preferred.
    - ❖ To facilitate the buy-in of team members, a servant leadership style should be preferred over an autocratic style.
    - ❖ Employee freedom and the organisational culture of the ICT section should be considered when adopting FMs.

The final versions of our content and association propositions are summarised next. Table 1 summarises our content propositions.

Table 2 summarises the association propositions.

Table 1. Summary of content propositions.

Content Proposition	Description
Proposition pC1	• The efficient use of FMs for system development necessitates the following: ❖ Developers should be trained in discrete mathematics and logic to produce a formal specification. ❖ Software tool usage should be included in FM courses. ❖ Attention should be paid to the role of the 4IR in promoting FMs. ❖ FM experts and consultants should form part of the training programme. ❖ Formal academic and industry-related qualifications are required for FM experts. ❖ Professional status should be available for FM practitioners, and attractive remuneration packages should be offered.
Proposition pC2	• The following would facilitate the training of FM developers: ❖ A formal specification language selected from algebraic, process-based, and model-based approaches should exhibit relative simplicity, yet be expressive. ❖ Functional support tools for requirements definition, formal specification, and subsequent transformation (refinement) into a correct system should be adopted.
Proposition pC3	• Prominent 4IR technologies include, amongst others, the IIoT, AR, C/EC, Printing 4.0, blockchain, and AI, of which AI may be the most prominent technology in guiding the path for FM usage as a technology.
Proposition pC4	• A Gartner–Hype™ cycle could be used to predict the industry's uptake of FMs. Coupled with this would be predictions on the post-adoption use of FMs, i.e., the sustainable use of FMs.
Proposition pC5	• In moving from the 4IR to the 5R, humans should play a central role in 4IR-5IR structures. ❖ Regarding robots as leaders, their ethical behaviour is paramount.
Proposition pC6	• As supported by a prominent 4IR structure, management's support of FMs adoption may be at the executive or cross-functional level: ❖ A transformational style with elements of consultative, participative, and adaptive styles may be preferred. ❖ To facilitate the buy-in of team members, a servant leadership style should be preferred over an autocratic style. ❖ Employee freedom and the organisational culture of the ICT section should be considered when adopting FMs.
Proposition pC7	• Modern 4IR frameworks, depicted as semi-structured diagrams, may still exhibit ambiguity that could be addressed through FMs.
Proposition pC8	• 4IR-5IR leaders, either robots or humans, should embody the leadership aspects of curiosity, learning agility, and a general leadership mindset. In addition to a conducive leadership mindset, 4IR-5IR leaders should perform the following: ❖ Exert influence and inspire subordinates and peers. ❖ Possess a learning agility linked to curiosity. ❖ Stimulate the acquisition and creation of knowledge. ❖ Be innovative, both regarding technical (4IR) aspects and commercialisation. ❖ Underwrite ethical behaviour towards colleagues, human or otherwise. ❖ Maintain transactional leadership and move towards transformational leadership, embedding consultative, participative, adaptive, and servant leadership styles.
Proposition pC9	• Maturity models for Leadership 4.0 frameworks ought to be enhanced for the 5IR and collectively adopted as part of 4IR-5IR FMs.

Table 1. *Cont.*

Content Proposition	Description
Proposition pC10	• FMs may elicit ambiguities in semi-formal 4IR structures, yet may incur other challenges, such as combining definitions and operations.
Proposition pC11	• FMs may be viewed as a technology, isomorphic to AI in the 4IR, making available to FM developers the advantages of the 4IR and the various technology adoption models and frameworks.
Proposition pC12	• FM adoption for reliable system development should be guided by underlying policies, legislation, and standards, including the emerging FMBoK and company-specific standards. ❖ The company should furthermore embark on a strategy for FM adoption.
Proposition pC13	• The initial adoption of FMs for reliable system development should support the ongoing, post-adoption use of these techniques in line with sustainable FMs use.
Proposition pC14	• Before adopting FMs, management and developers should perform the following: ❖ Conduct a thorough risk analysis and determine the return on investment (ROI). ❖ Investigate and study former successes of FMs. ❖ Liaise with early adopters of FMs.
Proposition pC15	• IT governors and company stakeholders should decide which part(s) of the SDLC could be augmented or replaced with FMs. Plausibly, not all traditional processes should be replaced.
Proposition pC16	• Owing to possible risk and ROI considerations, adopting FMs for system development would be a governance, i.e., a leadership-management (L-M) function, rather than an IT management function.

Table 2. Summary of association propositions.

Association Proposition	Description
Proposition pA1	• Training offered to employees may be technical for developers or managerial for upper management.
Proposition pA2	• A formal specification is associated with choices among the following: ❖ One or more specification styles. ❖ Tool support regarding automated, interactive, or hybrid reasoning. ❖ Transformation into a correct system.
Proposition pA3	• Governors and management ought to embrace the opportunities and technologies offered by the 4IR and, therefore, FMs as a technology.
Proposition pA4	• 4IR-IR technologies coupled with technology adoption structures inform the use of FMs as a viable 4IR-5IR technology.
Proposition pA5	• Legislation governs using 4IR-5IR technologies and determines the training offered to a company's FM practitioners, management, and governors.

3.7. Conceptual Framework

The framework depicted in Figure 6 conceptualises our FM adoption, having propositionalised leadership-management in the 4IR-5IR.

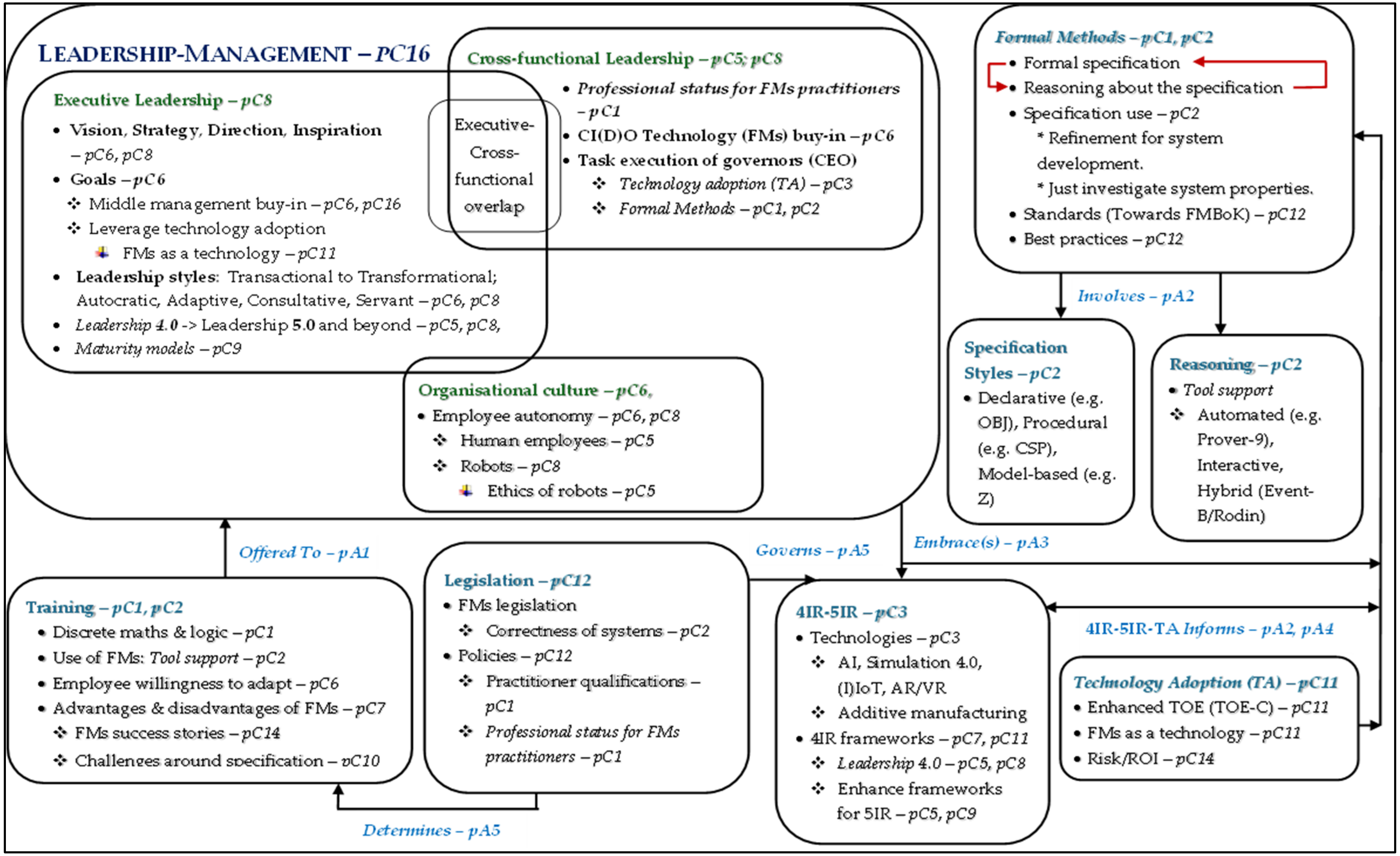

Figure 6. 4IR-5IR leadership-management FMs adoption framework (synthesised by the researcher).

4. Discussion

The framework in Figure 6 gives cognisance to the role of leadership-management, as embodied by executive leadership and cross-functional leadership, as well as the overlaps between these two. These are in line with the presentations in Section 3.3 on leadership, the Quality 4.0 and Leadership 4.0 frameworks discussed earlier. Central to these are the leadership styles and the role that the upper management can play in leveraging technology adoption, in our case, FMs adoption, but through transformational leadership, moving to adaptive, consultative, and servant leadership. Naturally, a company's organisational culture regarding the extent to which developers may accept these is vital. Hence, the researcher favours a consultative approach to introducing FMs as a technology in the 4IR-5IR eras. Training plays an equally important role in illustrating the notations of FMs in the form of specification work and reasoning about the specification, especially the value proposition to be gained using FMs. Tool support embedding a high level of user experience has been captured in the framework. Legislation around correct software development and the training of developers regarding these are included in the framework.

Aspects of FMs regarding the formal specification of a system, the options available in specification work, and reasoning about the specification are included. The framework captures the role of 4IR-5IR technologies to facilitate FMs adoption, similar to their role in advancing sustainable AI. Sustainability, i.e., the successful post-adoption of these techniques, is vital, and the framework acknowledges this. To this end, aspects of risk and the return on investment in adopting FMs for systems development have been included.

Many of the frameworks encountered in the literature are 4IR structures, and they should be enhanced over time to move into the 5IR. The framework acknowledges this important transformation, similar to refining specifications into running systems. Consequently, investigating the maturity of current 4IR frameworks to leverage these into the 5IR, giving cognisance to the human element, has been captured in our framework.

The governance structures of an organisation in the form of leadership-management play an important role in the successful adoption of these aspects in the framework depicted in Figure 6. Cognisance is given to the buy-in of cross-functional leadership to accept FMs by creating conducive environments for these techniques to be successful. The leadership style may make or break these initiatives and working towards achieving a professional status for FM developers and establishing lucrative remuneration packages should go a long way in achieving these goals.

Our framework, depicted in Figure 6, together with the above discussion on its content meet our objective presented in Section Research Questions and Objective.

5. Related Work

Previous approaches to adopting FMs concentrated on mission-critical systems, e.g., nuclear power plants and railway applications. Current approaches have moved into additionally considering complex business applications, e.g., ERPs [18], in adopting FMs [35]. Much emphasis is placed on tool support for FMs, and the performance of these tools, but the challenges indicated in Section 3.1 and other sections remain.

Online teaching of mathematics-related subjects has also been receiving attention. Naidoo and Reddy [65] investigated technology-based teaching methods for higher education mathematics in the 4IR in the post-COVID-19 era. They elicited several findings: lecturers created a safe online environment for student interaction; the said environments promoted technology-based teaching, engagement, and critical thinking; and the education experiences of the students facilitated their acceptance of technology-based teaching methods. These findings are important for promoting FMs through teaching these techniques to the younger generation. A difference with mathematics teaching may be that FMs in computing have a dynamic component, namely, a program that runs and moves from state to state, e.g., Z's state-based model.

Mpofu and Nemashakwe [66] explored leadership's crucial and multifaceted role in adopting 4IR technologies in emerging economies. The key aspects identified include a leader's vision and strategy; innovation; life-long learning; collaboration, partnerships and stakeholder engagement; change-management considerations; the allocation of resources; risk management; and governance, with their governance aspect linking with our leadership-management perspective. Other important perspectives identified in [66] include the upskilling and reskilling of leaders in a developing economy, linking with our training initiatives mentioned earlier (cf., propositions *pC1* and *pC2*), diversity management, and being technology proficient.

6. Conclusions

This article considered aspects around the use of FMs for sustainable correct software development; the advantages and disadvantages of using formality for system development were discussed in terms of the Quality 4.0 framework. Traditional aspects of management and leadership were investigated, and it was established that there is management in leadership and leadership in management. Regarding the 4IR, it was found that except for the researcher's work in this area, the literature is silent on establishing FMs in the 4IR. Aspects of leadership in the 4IR are covered in the literature, but the FMs aspect is likewise absent. Properties of FMs for software development covered formal specification, reasoning, and transforming the specification into code. Tool support with high levels of user experience was established as an important contributor to FMs' adoption.

The key ideas presented centred around the role to be played by upper management, i.e., governance structures coined leadership-management in our work. Organisational culture is prominent in the success of any transformational leadership exercise, hence embedding the said entity in the leadership-management entity in the framework. The augmentation of 4IR-5IR technologies to the process hinges on the premise that these technologies brought AI back from the trough of disillusionment over past decades. Technology adoption likewise emerged as an important consideration, given that FMs may be considered innovative. A conceptual framework was developed and presented in Figure 6.

6.1. Advancing Theoretical Knowledge

The L-M framework contributes to the body of knowledge at the intersection between leadership and using FMs for constructing correct software. As indicated before, approaches to addressing faulty software through FMs concentrated on technical aspects of the industry, and while these have made great strides, challenges remain, as discussed in Section 3.1 on FMs. The researcher believes the Figure 6 framework addresses this gap by considering the FMs challenge from the viewpoint of what leadership can achieve, i.e., a leadership-management framework.

6.2. Practical Implications

For the most part, the development of correct software is seen exclusively as the responsibility of a company's ICT section. Managers may take an interest in these processes but might not be further involved. The researcher believes that the L-M framework may convince managers and leaders to be involved at a further level without interfering autocratically with the workings of the company's ICT. The framework may well move upper management to become more involved in strategic decisions at a technical level through transformational leadership embedded in participative and servant leadership styles. It is hoped that the framework could act as a roadmap for managers, indicating the important role they could play in their company's ICT processes. The full impact of the framework and how it could be applied in a real-world organisational setting will become clearer once we conduct cases in companies, as indicated in the future work section.

6.3. Limitations

A present limitation of our work is that it is conceptual, and the framework in Figure 6 may be considered high-level, i.e., it is essentially a problematisation framework that depicts the challenges or aspects of 4IR-5IR leadership-management to be addressed in

FMs' adoption. The framework is also a static structure and is devoid of a dynamic component that would guide governors in the precise sequence of steps to follow in the adoption of FMs in the 4IR-5IR. Future work, below, considers, amongst other things, these aspects.

6.4. Future Work

Future work in this area may be pursued along several avenues. As indicated above, the framework in Figure 6 is conceptual and qualitative. It presents the aspects to be investigated and synthesised to drive the adoption of FMs, their ongoing use for systems development, and the role that leadership-management can play in facilitating these processes. Figure 6 may, therefore, be looked upon as a problematisation framework, eliciting the challenges that should be addressed in facilitating the adoption of FMs through leadership-management. In line with problematisation theories, aspects of paradigms, metaphors, and puzzle-solving activities [27] would come into play. Following this line of thought, our work challenges the status quo of solely addressing FMs' adoption from a technical viewpoint.

Having enhanced the framework through problematisation, it would be refined by conducting surveys among FM practitioners and thought leaders, in the context of the developing economy where the researcher resides [66,67]. The first round of surveys would be qualitative, utilising an interview guide, having been evaluated for trustworthiness beforehand. Typically, the findings from the interviews are analysed with ATLAS.ti. A further enhanced framework would result, and such framework would be yet further enhanced through a quantitative survey of which the research instrument would have been tested for validity. It is anticipated that several entities in the framework will be enhanced through the said surveys. Following these initiatives, the next step would be to develop a solution framework for the enhanced framework, in which entities would become sub-frameworks of their own.

Finally, the solution framework that results from the above activities would be exercised in companies using a case study approach. Our framework is hoped to make a valuable contribution to the acceptance of FMs in the 4IR-5IR through leadership-management.

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