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Sustainability and digitalisation: Using Means-End Chain Theory to determine the key elements of the digital maturity model for research and development organisations with the aspect of sustainability

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A B S T R A C T

Organisations are under pressure to digitally transform and become more sustainable. Thus, the convergence of digitalisation and sustainability is inevitable. There are several Digital Maturity models that help companies to develop their digital roadmaps, however, none of them have been developed for Research and Development (R&D) organisations. Additionally, none of these models include the dimension of sustainability. In this paper the authors used the Means-End Chain method to determine which are the key dimensions of the digital maturity model tailored for R&D, as well as to investigate the link between digital transformation and sustainability. The results show that although technologies are important, they cannot successfully transform the organisation on their own. They must be supported by people and culture change. The results also highlighted that sustainability is high on the agenda and cannot be ignored when progressing towards the higher level of Digital Maturity. The findings may serve as a reference for any organisation that is building or revising its digitalisation or sustainability strategies. It highlights the important dimensions that should be considered and prioritised when preparing the transformation roadmap. These dimensions are tailored for R&D but can be a good indication for any other type of organisation.

A R T I C L E I N F O

Keywords:
Sustainability;
Digitalisation;
Digital transformation;
Means-End Chain Theory (MEC);
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1. Introduction

To remain competitive in today's market and to assure long-term survival, organisations must continuously develop innovative, high-quality products and services and renew their way of operating [1]. Therefore, they are under tremendous pressure to transform. It is the case for organisations from both developed and transitioning countries [2]. The majority of them are taking advantage of new technologies, pursuing their "digital transformations" [3–5]. At the same time, companies must reduce their carbon footprint and become more sustainable overall [6, 7]. These two strategies are interconnected and some of these connections have been demonstrated in [8], where the authors argue that they are positively related. It can be stated that a given company that transforms itself becomes more efficient and thus automatically more sustainable. On the other hand, new technologies offer resources that can be applied to accelerate sustainability [7, 9].

Additionally, recent events (mainly the global pandemic that started in early 2020) highlighted the growing need for organisations to become more digitally mature. This is supported by the emerging research including the study of Fletcher and Griffiths [10] suggesting that VUCA environments (VUCA stands for Volatility, Uncertainty, Complexity and Ambiguity) strengthen the need for digital transformation. After analysing the effects of global pandemic, they even suggest, that digital is no longer an option but became a necessity. Such events affect more severely less digitally mature organisations. Another research by Vandana and Ashutosh [11] supports this observation.

The task of continuous reinvention of a given organisation in many cases is performed by Research and Development departments (R&D). As leaders of such creativity and innovation, R&D organisations are at the forefront of progress. They contribute towards new technologies, products, and manufacturing processes more than any other entity. It is their mission to apply innovation to make new processes more efficient, products more attractive and cheaper, and overall to help to become more efficient, generate less waste and reduce the impact on the environment, business, and society [12].

A good way to progress on such a transformational journey is to apply a concept of digital maturity. Assessing the state of digital maturity and deciding how to proceed to a higher maturity level can help to create transformation programs using a systematic approach and eliminate blind spots. Digital maturity models are used for prescriptive, descriptive and comparative purposes [13, 14]. Many of them have been developed by organisations to assess their processes, identify improvement areas and use them to drive the way they operate [15]. Maturity assessments can be applied to an entire organisation or part of it, and can also be specifically developed and applied to certain aspects of any business process. The usual way of employing a maturity model is to use it to assess an organisation's current maturity and then prepare a strategy for the future to achieve a higher level.

Although there are several publications about digital maturity within the existing literature, the authors noticed that there is a gap when it comes to digital maturity tailored to the needs of R&D organisations, and they hope that this publication can contribute towards closing this gap. It attempts to describe which digital maturity dimensions should be considered to fit into R&D specifics. It also tries to explore the relation between digital transformation and sustainability.

The authors' understanding of sustainability is based on the "Brundtland Report", which was published in 1987 by the World Commission on Environment and Development (WCED) [16]. In this report sustainability or sustainable development is described as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". It is based on three pillars: social, economic and environmental sustainability [17]. Currently, both sustainability and digitalisation strategies are at the top of most companies' agenda. Even if this is the case, in many organisations both strategies are operating in parallel, being executed by separate departments with people with different skillsets. Recently, however, there is emerging scientific evidence that digitalisation and sustainability are interconnected [8, 18]. There is an emerging opportunity to join efforts to accelerate sustainability goals by using digital technologies. It is worth noticing the work of Gupta et al., who presented the Digitalisation–Sustainability Matrix, where they researched how technologies impact Sustainable Development Goals (SDGs) [19].

The authors firmly believe that there is no responsible digitalisation without considering the dimension of sustainability. A digitally transformed company becomes more efficient, generates less waste and uses fewer resources, which makes it more sustainable.

The first research goal of this study was to determine the key elements of a digital maturity model tailored for such an R&D organisation. The focus was on the model's key dimensions (often also referred to as "goals" or "values"). The second goal was to conduct a preliminary study on the sustainability dimension as part of the digital maturity model, considering the fact that digital technologies have a big potential to accelerate sustainability [20]. The objectives were achieved by applying a 2-step approach. Firstly, the authors prepared an initial set of dimensions based on the literature review of the existing digital maturity models. Secondly, by using the Means-End Chain (MEC) method, they refined this initial set and suggested a usable compromise which can be used for an R&D digital maturity model. Information for the MEC was taken from the outputs from interviews conducted with experts from both inside and outside R&D.

This paper starts with the literature review and the description of methods used. These are then followed by empirical data analysis, discussion of results and conclusions, with suggestions for further potential research areas.

2. Literature review

The authors conducted the literature review according to the guidelines proposed by Kitchenham at Keele University [21]. They searched Google Scholar, SCOPUS, EBSCO and ProQuest for the terms "Digital AND Maturity AND Literature AND Review". The initial result showed 292,000 entries in Google Scholar, 168 in SCOPUS, 834 in ProQuest and 32 in EBSCO. To limit the results to the most relevant ones, the authors applied several filters. As the various repositories were constructed in different ways, it was impossible to apply the same filters on all of them in the same way so, in order to ensure that the review was comprehensive, the authors applied filters where it was possible without changing the number of results in the repositories where such filters did not exist. For example, ProQuest offered the filter called "literature reviews" which reduced the number of papers initially found from 834 to 151, however, such filter did not exist in Google Scholar, SCOPUS and EBSCO. The next level of filters applied was the language (English), which reduced the number of results in SCOPUS from 168 to 164. An additional filter applied was to include results that were "peer reviewed", which reduced the number of results in ProQuest to 149 and EBSCO to 27. The last filter applied was to look for results in the paper title and this reduced the number of results to 259 (Google Scholar 8, SCOPUS 3, ProQuest 149, EBSCO 99). The authors analysed these 259 results, eliminated overlaps across repositories and selected 8 publications which were relevant in the first stage of the research. These publications were used to find the existing most relevant digital maturity models, determine if there are gaps related to specifics of Research and Development organisations and which potential dimensions of the existing models could be adapted and used for building a model that is better tailored to R&D specifics. Table 1 lists the literature selected by the authors.

The nine models shown in Table 2 represent the results of the authors' analysis of the models developed by both academics and practitioners. More models were found but either their research was not completed or there were not enough details about the model, making it too open to individual interpretation and thus too difficult to use, making the result unpredictable.

Table 1 Literature review output – selected publications

Publication name	Authors	Year published
Multi-Attribute Assessment of Digital Maturity of SMEs [22]	Kljajić Borštnar, M., Pucihar, A.	2021
Digital Maturity Models: a systematic literature review [23]	Ochoa-Urrego, R.-L., Peña-Reyes, J.-I.	2021
Industry 4.0 Roadmap: Implementation for Small and Medium-Sized Enterprises [24]	Cotrino, A., Sebastián, M.A., González-Gaya, C.	2020
Towards a Comprehensive Exploration and Mapping of Maturity Models in Digital Business: A Systematic Literature Review [25]	Gandhi, A., Sucahyo, Y.G	2020
Digital Transformation Maturity: A Systematic Review of Literature [26]	Teichert, R.	2019
Digital Maturity Models for Small and Medium-sized Enterprises: A Systematic Literature Review [27]	Williams, C., Schallmo, D., Lang, K., Boardman, L.	2019
An Industry 4.0 maturity model proposal [28]	Santos, R.C., Martinho, J.L.	2019
Development of an Assessment Model for Industry 4.0: Industry 4.0-MM [29]	Gökalp, E., Şener, U., Eren, P.	2017

Table 2 Literature review output – Digital Maturity Models

Model/Research name	Research context	Maturity levels	Dimensions
IMPULS Industry 4.0 Readiness [30]	Industry 4.0 readiness	6 maturity levels (Outsiders, Beginner, Intermediate, Experienced, Expert, Top performers)	6 dimensions (Strategy & Organisation, Smart Factory, Smart Operations, Smart Products, Data-driven Services, Employees)
Industry 4.0 / Digital Operations Self-Assessment [31]	Digital readiness for Industry 4.0	3 maturity levels (Vertical Integrator, Horizontal Collaborator, Digital Champion)	6 dimensions (Business Models, Product & Service, Portfolio Market & Customer Access, Value Chains & Processes, IT Architecture, Compliance, Legal, Risk, Security & Tax, Organisation & Culture)
SIMMI 4.0 [32]	Industry 4.0 maturity	5 maturity stages (Basic Digitisation, Cross-departmental Digitisation, Horizontal and Vertical Digitisation, Full Digitisation, Optimised Full Digitisation)	3 dimensions (Vertical Integration, Horizontal Integration, Cross-sectional Technology Criteria)
Acatech Industry 4.0 Maturity Index [33]	Industry 4.0 maturity	6 maturity stages (Computerisation, Connectivity, Visibility, Transparency, Predictive Capacity, Adaptability)	4 structural areas (Resources, Organisational Structure, Information Systems, Culture)
DREAMY (Digital REadiness Assessment MaturitY model) [34]	Digital readiness for Industry 4.0	5 maturity stages (Initial, Managed, Defined, Integrated and Interoperable, Digital-Oriented)	5 structural areas (Design and Engineering, Production Management, Quality Management, Maintenance Management, Logistics Management)
A maturity model for Industry 4.0 Readiness [35]	Industry 4.0 maturity	Likert scale maturity levels (from rating 1= “not important” to rating 4 = “very important”)	9 dimensions (Strategy, Leadership, Customers, Products, Operations, Culture, People, Governance, Technology)
360 Digital Maturity Assessment [36]	Digital readiness for Industry 4.0	6 maturity stages (None, Basic, Transparent, Aware, Autonomous, Integrated)	5 digital dimensions (Governance, Technology, Connectivity, Value Creation, Competence)
HADA http://hada.industriaconectada40.gob.es/	Model developed by Spanish Government	6 maturity stages assigned by point system 0-1000 based on survey results (Static, Aware, Competent, Dynamic, Reference, Leader)	5 dimensions (Strategy and business model, Processes, Organisation and people, Infrastructures, Products and services)
Multi-Attribute Assessment of Digital Maturity [22]	Digital Maturity of SMEs	4 maturity stages (Lagging behind, Initial, Advanced, Digital winner)	2 dimensions (Digital capability, Organisational capability)

The authors found the literature review very insightful. It showed that the topic of digital maturity is increasingly on the agendas of researchers and practitioners. It was also interesting that there is a big overlap between digital maturity and Industry 4.0 readiness, and in many cases these terms were used as synonyms. They concluded, however, that while Industry 4.0 readiness was mainly targeting industrial applications, digital maturity can be used across a wider set of organisations, including public services or non-profit. The review also showed that relevant research and adoption accelerated over the last 10 years, demonstrating the growing need for frameworks that would help organisations build their roadmaps and strategies in a structured and unbiased way.

The further explanation of how authors used the outcomes from this literature review and arrived at the initial set of dimensions is described in more detail in chapter 3: "Research design". It is also worth noticing that none of the existing maturity models described in the literature contains the sustainability dimension, which prompted the authors to include it in their proposed set of dimensions and then discuss further with experts whether it should or should not be considered.

3. Research design

3.1 General design

To address the research questions, the work was organised into two main phases as shown in Fig. 1. In Phase 1, the authors wanted to find and analyse the research already available. This served two goals. Firstly, the authors wanted to validate if there is a gap in the existing literature in relation to R&D organisations to ensure the scientific value and contribution of their work. The second goal was to derive the initial set of dimensions to be validated in Phase 2. In this phase the authors conducted interviews with experts and applied the Means-End Chain method to arrive at the final set of dimensions addressing the needs of research and development.

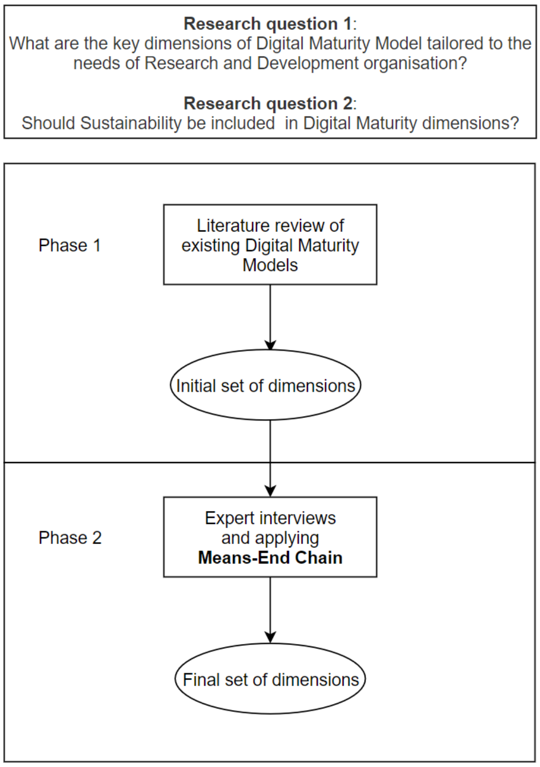

Fig. 1 The structure of the research

To prepare the initial set of dimensions, the authors summarised and grouped the output from the literature review (dimension elements from Table 2) into three categories, namely, "External factors", "Internal factors" and "Organisation" as shown in Table 3.

From "External factors", the authors suggested the following "Products" and "Services" as initial dimensions. From "Internal factors", the most prevailing to be added to the initial list were "Operations" and "Facilities", and from the "Organisation" side the authors suggested using "People" and "Strategy". Additionally, the authors added the "Sustainability" dimension to test its viability as part of the digital maturity model of an R&D organisation. The rest of the elements in Table 2 did not need to form separate dimensions. For example, "Business Models" can be classified as part of "Operations" similarly to "Compliance, Legal, Risk, Security and Tax". "IT architecture" can be part of "Facilities" and does not require a separate dimension to be formed. The authors believed that the initial proposed set of dimensions catered well for all the elements identified during the literature review.

To verify this initial list of dimensions and to refine the findings, the authors applied the Means-End Chain (MEC) method. This method is widely known and used in marketing, but has not previously been used to compile and verify the elements of digital maturity. However, it was used in several studies outside of marketing that inspired the authors to apply it in their research. For example, in project management, in 2010 Verburg et al. used MEC to determine critical success factors for project managers in virtual work settings [37]. Later, in 2018, Chen et al. used MEC for innovation research program performance evaluation [38].

Table 3 Initial grouping of the dimensions

Model/Research name	External factors	Internal factors	Organisation
IMPULS	Smart products Data-driven services	Smart factory Smart operations	Employees Strategy and organisation
Industry 4.0 / Digital Operations Self-Assessment	Market & customer access	Business models Product & service portfolio Compliance, legal, risk, security & tax IT architecture Value chains & processes	Organisation & culture
SIMMI 4.0		Vertical integration Horizontal integration Digital product development Cross-sectional technology criteria	
Acatech Industry 4.0 Maturity Index		Resources Information systems	Resources Information systems
DREAMY (Digital REadiness Assessment MaturitY model)		Process monitoring and control Technology	Organisation
A maturity model for Industry 4.0 Readiness	Customers product	Operations Technology	Strategy Leadership Culture People Governance
360 Digital Maturity Assessment		Technology Connectivity Value creation	Governance Competence
HADA	Products and services	Infrastructure Strategy and business model Processes	Strategy and business model Organisation and people
Multi-Attribute Assessment of Digital Maturity		Digital capability	Organisational capability

3.2 Means-End Chain

The Means-End Chain (MEC) method is based on the attributes–benefits–values/goals sequence that forms a means-end chain. It was used initially by Gutman to understand the perceptions and motivations of consumers when they make their purchasing choices [39]. In that sense, it connects product or service attributes to the consequences produced by these and the latter to values. The MEC method is based on the sequence or hierarchy shown in Fig. 2 [40]. The links are identified by means of interviews conducted with the focus group individuals (customers, experts, etc.). The laddering interviewing technique is used for the elicitation. Laddering involves a tailored reviewing format using a series of directed probes, typified by the "Why is it important to you that…" question [41]. The answers are explored further, and a ladder of constructs is created. The soft laddering method [42] is the recommended technique with a relatively small sample size (<50) and research of an exploratory nature [43].

In the case of this research, the values are the dimensions of the digital maturity model that are selected by experts for their attributes as well as their benefits. The links between products, values and attributes were identified through interviews conducted with subject matter experts following the laddering technique [41]. These interviews were conducted by asking about the attributes, why they are important (what benefits would be realised) and what values/goals they would serve. For example, if the goal is to have "Smart operations and research" in place, then products can be developed faster (benefit). To achieve this benefit, there is a need to "digitise information" (attribute) or have "digital platforms in place" (another attribute).

Once the interviews were finished, the Implication Matrix (IM) and Hierarchical Value Map (HVM) were created by LadderUX software to analyse the results. The Implication Matrix is a tabular representation of the interview outcomes, while the Hierarchical Value Map (HVM) visually links attributes, benefits and goals. Examples of the HVMs created during this research can be found in the "Discussion" section (Figs. 3-6).

To determine the order of importance for all the attributes, benefits and dimensions, the authors calculated their centrality as described in the following section.

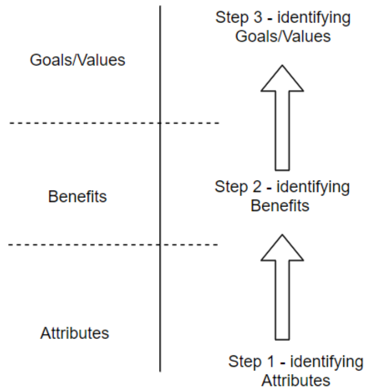

Fig. 2 The sequence flow of the Means-End Chain method

3.3 Calculating centrality

Centrality is defined as the ratio of in-degrees plus out-degrees of a particular element over the sum of all cell-entries in the implication matrix [44]. It highlights those mentioned by most of the experts. The equations below represent the Implication Matrix (IM) and illustrate how the centrality is calculated. The columns of the IM are represented by index i – from 1 to the n^{th} element, the rows by index j – from 1 to the n^{th} element. Column S includes the sum of "out" elements in the row and column T includes the sum of "out" elements from both relevant rows and columns (the figure in column S). Column C displays the calculated centrality.

$$IM = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1i} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2i} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots & \cdots & \vdots \\ a_{j1} & a_{j2} & \cdots & a_{ji} & \cdots & a_{jn} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{ni} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

Calculation of the values of the elements is shown below:

$$S_j = \sum_{j=1}^{n} a_{ji} \tag{2}$$

$$T_j = S_j + \sum_{j=1}^{n} a_{ji} \quad (3)$$

$$\sum T = \sum_{j=1}^{n} T_j \quad (4)$$

Finally, the centrality of each element is calculated as:

$$C_j = \frac{T_j}{\sum T} \quad (5)$$

4. Empirical data analysis

The process of interviewing started on 26 May 2020 and lasted until 2 February 2021. Considering the situation with the global pandemic (COVID-19) and the physical location of the experts, the authors conducted interviews using Microsoft Teams. All of them were recorded and stored in Microsoft Stream. At this stage, 32 senior experts (28 men and 4 women) from various functions and companies were interviewed, of whom two experienced technical difficulties and were not included further in the study. These experts are connected to digital transformation either within their own organisation or participating in the digital transformation of several organisations as a partner or consultant. They reside in both the Americas and Europe and work in companies of various sizes, from a single consultant to multinational corporations with over 200 000 employees. It was very important to ensure a wide representation of experts and not to limit the research to specific segments or industries. These segments and industries included tech start-ups, telecommunication, recruitment, research and development, fast-moving consumer goods (FMCG), manufacturing, management consulting, technology companies and academia. The authors wanted to collect both R&D views as well as external views to eliminate blind spots and biases. The interviewees resided in the following countries: Canada (1), Denmark (1), France (3), Luxembourg (2), Netherlands (2), Spain (2), UK (15) and USA (6). Authors' criteria for selection were not specifically related to the countries but to the area of expertise of the interviewee and to the type of their organization. Authors wanted to get the view from both inside or outside the R&D, from small and big organisations and they believe that it has been achieved.

When it comes to the question about the number of interviews to conduct in order to obtain meaningful results, the authors used the study conducted by Guest et al. [45]. In this publication they discuss the data saturation and variability in extracting information from interviews to determine how many interviews are enough to get meaningful results. In their experiment they concluded that to achieve meaningful themes and useful interpretation it takes as little as 6 to 12 interviews for this kind of study. They caution, however, that in some cases 12 interviews may not be enough. For example, if the "selected group is heterogeneous, the data quality is poor, and the domain of inquiry is diffuse and/or vague. Likewise, you will need larger samples if your goal is to assess variation between distinct groups or correlation among variables". With that in mind, considering that the population selected for this research is relatively homogeneous (each of the interviewees has certain expertise in the field of digital transformation) and to accommodate a certain margin to eliminate insufficient data, the authors decided to conduct 30 interviews. Patterns were noticed after 12 of them, when the goals, attributes, and benefits started to repeat themselves (although some of them were named differently like "Employees" versus "People", the meaning was the same).

With the initial set of goals (dimensions), the in-depth interviews were conducted by asking the following questions: "Which attributes would need to be in place to become digitally mature?" and "Why are these attributes important?". The purpose of the first question was to identify the attributes, the purpose of the second was to identify benefits and goals/values. After each interview, the values (goals) were noted down together with their links to the benefits, as well as the attributes that were mentioned by the experts. These links were entered into the LadderUX software [46], which generated the Implication Matrix (with calculated centralities) as well as the Hierarchical Value Map showing graphically these connections. After several interviews the set of values evolved to "Smart operations and research" (to include the scientific aspect as well as the organisational), "Smart facilities", "Smart products and services", "People", "Strategy and organisation" and "Sustainability", which was consistent throughout the majority of the interviews. It also became evident that there is a need to standardise responses as much as possible to avoid overlap (for example, some experts referred to a dimension called "Employees", some to "People" and some to "People and Culture"). To represent the degree of the central role of each element [47], the authors calculated the centrality. Centrality can be interpreted as a key element that determines the importance of the goals, benefits and attributes. Once calculated, the elements in each group were arranged from the largest to the smallest value of their centrality.

Overall, the authors collected 111 elements that were grouped into 7 Goals (Dimensions), 47 Benefits and 57 Attributes. After calculating each element's centrality, they were sorted by it. The tables below show each of the elements from the largest to the smallest value of centrality. The Goals are shown in Table 4 and Benefits and Attributes in Table 5.

Table 4 List of the Goals

	Goal	Centrality
G1	Smart operations and research	0.076
G2	People	0.057
G3	Sustainability	0.051
G4	Strategy and organisation	0.024
G5	Smart facilities	0.02
G6	Smart products and services	0.013
G7	Smart innovation	0

Table 5 Summary of Benefits and Attributes

	Benefit	Centrality		Attribute	Centrality
B1	Faster product development	0.051	A1	Data management	0.052
B2	Increased efficiency of operations	0.051	A2	Education of people	0.035
B3	Innovative workforce	0.047	A3	Analytics tools	0.013
B4	Faster process development	0.046	A4	Knowledge creation and management platform	0.013
B5	Faster response to market dynamics	0.037	A5	Smart platforms	0.009
B6	Skilled workforce	0.032	A6	Communication	0.009
B7	New revenues	0.019	A7	Collaboration tools	0.007
B8	More value for customers	0.019	A8	Digitalise the equipment	0.006
B9	Profitability	0.013	A9	Sharing scientific information	0.006
B10	Understand carbon footprint	0.012	A10	Sharing experimental information	0.006
B11	Increased competitiveness	0.011	A11	Digital twins/simulations	0.005
B12	Understand the strategy	0.009	A12	Access to right talent	0.005
B13	Outcome-based pricing	0.008	A13	Sustainability score dashboard	0.005
B14	Driving reputation	0.008	A14	Efficiency dashboards	0.004
B15	Increased customer satisfaction	0.006	A15	Continuous improvement for process and culture	0.004
B16	Lower energy consumption	0.006	A16	Digitise information	0.003
B17	Lower emissions	0.006	A17	Product tracking technology	0.003
B18	Less waste	0.006	A18	Change management process	0.003
B19	Operational flexibility	0.006	A19	Enabling experimentation	0.003
B20	Improved health and safety	0.006	A20	Efficient and secure IT	0.003
B21	Educated workforce	0.006	A21	Sharing data with suppliers and customers	0.003
B22	Lower carbon footprint	0.006	A22	Shared environmental data	0.003
B23	Reduced time to market	0.004	A23	Shared customer data	0.002
B24	People understand emerging technologies	0.004	A24	Predictive maintenance	0.002
B25	Limit the negative consequences of operations	0.004	A25	Smart horizontal and vertical integration	0.002
B26	Effective usage of available data	0.004	A26	Capturing value creation	0.002
B27	New customers	0.004	A27	Meaningful data exchange	0.002
B28	Market adaptability	0.004	A28	Sourcing green energy	0.002
B29	Increased employee satisfaction	0.004	A29	Sustainability assessment process	0.002
B30	Making right decisions	0.004	A30	Innovation performance reviews	0.002
B31	Longer asset lifecycle	0.004	A31	Innovation workshops	0.002
B32	Product life cycle control	0.004	A32	Innovation strategy	0.002
B33	Right pricing	0.004	A33	Technology-based intelligence	0.002
B34	Improved quality of products and services	0.004	A34	Innovation governance	0.002
B35	Faster pace to sustainability	0.004	A35	Process automation	0.002
B36	Articulate and share organisational goals	0.002	A36	Usage of standards	0.002
B37	Proactiveness	0.002	A37	Automatic commissioning of the equipment	0.001
B38	Enhanced product life	0.002	A38	Collaboration with academia	0.001

Table 5 (Continuation)

	Benefit	Centrality		Attribute	Centrality
B39	Data-driven decision-making	0.002	A39	Measuring environmental impact	0.001
B40	Ability to measure impact	0.002	A40	Leadership fit	0.001
B41	Efficient resource usage	0.002	A41	Distributed team	0.001
B42	Supply chain transparency	0.002	A42	Agile strategy	0.001
B43	Positive impact on supply chain	0.002	A43	Carbon offsetting activities	0.001
B44	Attract investors	0.002	A44	Rotating people across organisation	0.001
B45	Common IT platforms	0.001	A45	Coaching/mentoring process	0.001
B46	Knowledge created and shared	0	A46	Circular economy principles	0.001
B47	Optimised use of budget	0	A47	Supply chain carbon footprint	0.001
			A48	Drone technology	0.001
			A49	Image recognition	0.001
			A50	Digital hiring tools	0.001
			A51	Governance	0.001
			A52	ISO 14001	0.001
			A53	Digitalise partnerships	0
			A54	LIMS system in place	0
			A55	Production data tracking and linking with product	0
			A56	Leverage external partners	0
			A57	Budget	0

The Hierarchical Value Map (HVM) generated by Ladderux.org [29] consisted of 242 ladders with a total of 708 links. 475 of these links were direct and 233 were indirect. The number of elements and links made the visualisation of the entire HVM difficult for the purpose of this publication. To make the ladder examples presentable, the authors carried out a separate analysis for the top three dimensions and show them in more detail in chapter 5 "Discussion".

5. Discussion

After the round of interviews, the authors arrived at 6 dimensions. These dimensions are: "Smart operations and research", "People", "Sustainability", "Strategy and organisation", "Smart facilities" and "Smart products and services". Due to the fact that the centrality of the "Smart innovation" dimension was 0, it was removed from the final list (see Table 4).

Out of 47 collected benefits, the 5 most prevailing ones by centrality were "Faster product development", "Increased efficiency of operations", "Innovative workforce", "Faster process development" and "Faster response to market dynamics". Four of these are related to efficiency and the speed of the response to the market, but it is worth noticing that the third most central element was related to people and innovation. It could be said that an innovative workforce benefits from the technology and education, which in return helps to achieve the goals of the organisation.

The 57 collected attributes are a mixture of technologies, tools, platforms (e.g. "Data management", "Collaboration tools", "Digital twins/simulations" etc.) and processes (e.g. "Collaboration with academia", "Sustainability assessment process", "Usage of standards", etc.) The top ones by centrality are "Data management", "Education of people", "Analytics tools", "Knowledge creation and management platform" and "Sustainable operations". It is understandable that the "Data management" had the highest centrality score. This is required as a foundation for any operations to become "data- driven". It was very interesting to see that the "Education of people" was placed in second position, which confirms that digitalisation is not purely dependent on technologies. On the contrary, the right education of people will be a critical attribute driving the culture shift required to move to the higher level of digital maturity. "Analytics tools" were placed in third position, which underlines the need for tools to act on the collected data. The explosion of various analytics tools offerings on the market confirms the importance of this attribute. Next in line, "Knowledge creation and management platform" seems an important attribute especially for R&D organisations where scientists create and share both scientific and organisational knowledge. As a side observation from the interviews, the authors noted that in many organisations the knowledge is scattered in various repositories, creating a challenge for people to find the right information. What is more, often there is not a single digital tool which would connect these separate pockets of knowledge. This was more visible in large organisations with various legacy knowledge repositories. However, the majority of them stated that deploying a digital tool that will connect various repositories and help to extract value from them was one of their priorities in order to speed up future development and accelerate research.

To further focus on the first three dimensions, the authors separated them from the other elements in the LadderUX tool [46]. Fig. 3 shows the dimension "Smart operations and research", focusing on the benefit B1 – "Faster product development".

The authors observed that "Data management" and "Analytics tools" were the first attributes contributing towards "Faster product development". However, it is worth mentioning the "Knowledge creation and management platform" - although it is a technical tool, it fosters collaboration and teamwork as people will use it to document their work and to learn from what was already done in the past on any given topic or project.

A very similar pattern could be observed for "Faster process development". This is due to the fact that, usually, to produce any given product faster, the production or manufacturing process needs to be more efficient.

Interestingly, taking a closer look at the three further benefits with the largest centrality, it can be concluded that their key attributes are the same as those previously described and illustrated in Figs 5 and 6. These benefits are "Increased efficiency of operations", "Faster response to market dynamics" and "Faster pace to sustainability" (see Fig. 4). The important thing to notice in this ladder is the link between digital transformation and sustainability. It shows that, by achieving the goal of "Smart operations and research", the organisation will not only become more efficient and faster in terms of product development and manufacturing. It clearly also accelerates the path to sustainability and proves that, by moving up on the digital maturity curve, companies become more sustainable.

Fig. 5 shows the simplified HVM for the "People" dimension. The simplification eliminated elements with fewer than 5 connections.

For this dimension the emphasis should be put on the education attribute. Arming people with the right skillset future-proofs the existence of the organisation. Education also makes people more aware of the context of digitalisation and its purpose, which makes it easier to accept change. Additionally, education, training and overall career development have a big influence on employee satisfaction and a significant impact on their performance, driving the performance of the organisation [48].

To visualise the sustainability, the authors disabled all other dimensions in the laddering tool and then set cut-off values for connections equal to or less than 2 for the attributes and benefits, ending up with the ladder shown in Fig. 6.

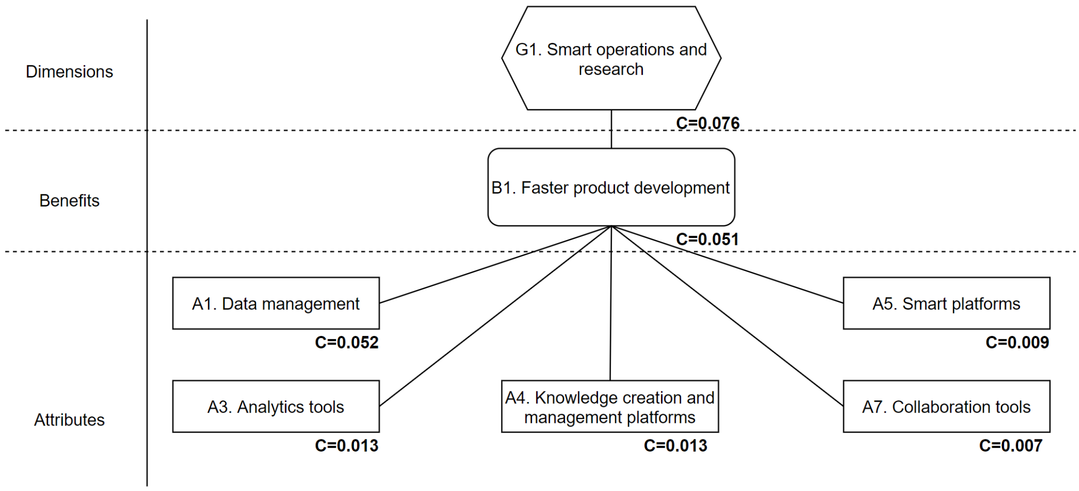

Fig. 3 Simplified ladder diagram for "Smart operations and research" (Faster product development benefit)

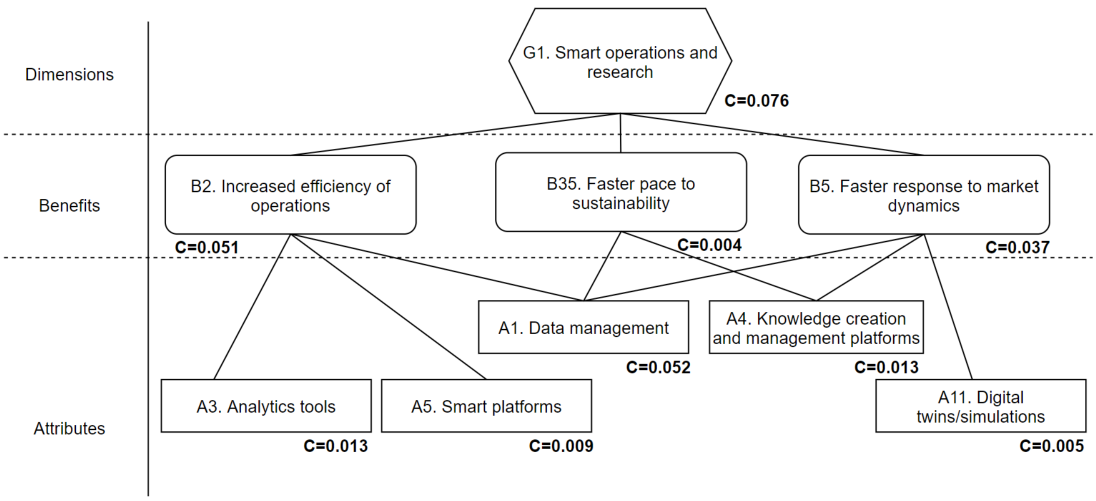

Fig. 4 Simplified ladder diagram for "Smart operations and research"

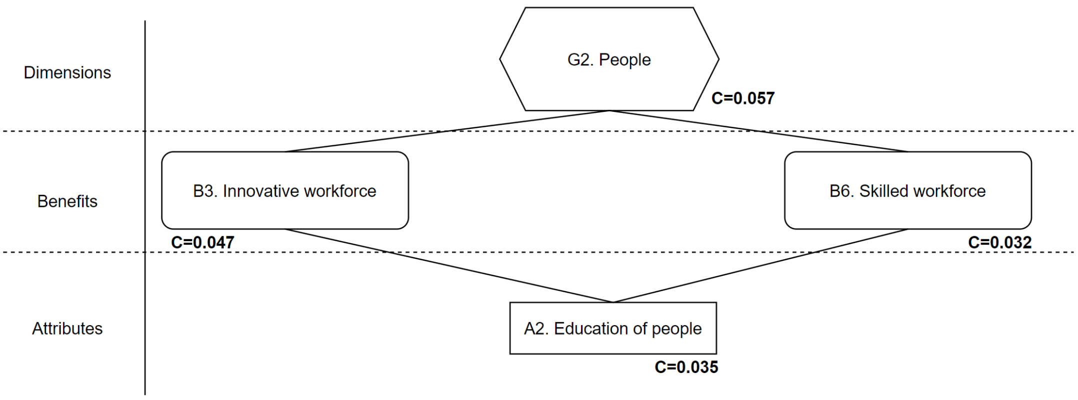

Fig. 5 Simplified ladder diagram for "People" dimension

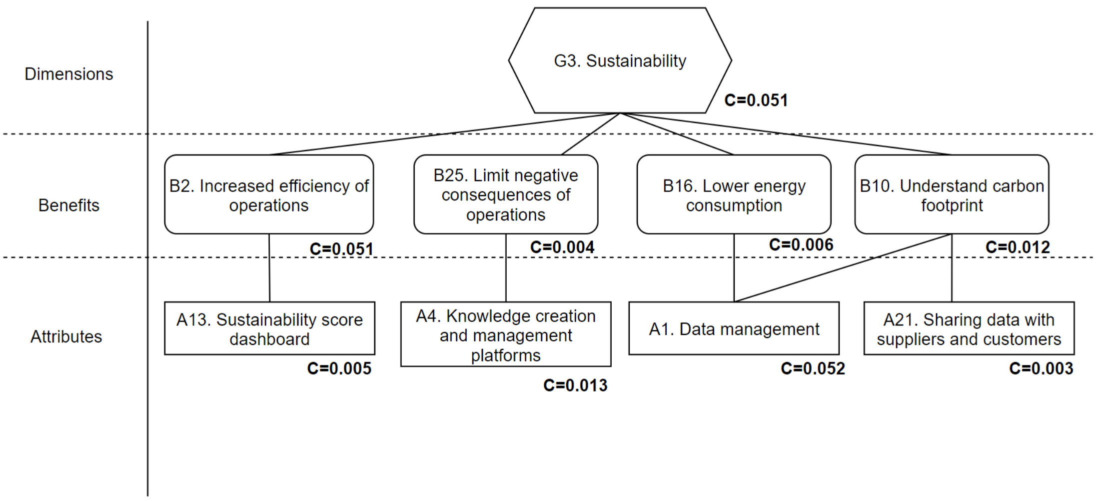

Fig. 6 Simplified ladder diagram for "Sustainability" dimension

It was evident again that “Data management” is a key attribute, contributing to lower energy consumption, by enabling data-driven decision-making. It also allows a better understanding of the carbon footprint. As it forms the foundation for digitalisation, it is an important contributor towards better sustainability.

In order to move to a higher stage of digital maturity, the data management (the attribute that comes with the highest centrality from all 59), supported by the analytics tools (the attribute that came third), should be the first ones considered when preparing the digital roadmap for the organisation. If the budget is limited and requires prioritisation, these should be the top priorities, contributing to most of the goals, including “Sustainability”.

Finally, the authors carried out a sensitivity analysis to understand how each single attribute influences the dimensions. For this, they calculated the values of the dimensions’ maturity separately for each attribute, setting its value to 1 (full influence on the dimensions) while setting all the other attributes’ values to 0 (no influence on dimensions). The result is shown in Fig. 7. Such analysis can be very useful for selecting the areas of focus when creating plans and planning the resources needed for achieving higher levels of maturity. For example, focusing solely on “Real-time data collecting and sharing” and investing most of the effort in improving the data management has a major positive influence on the overall digital maturity for most of the dimensions. It could be imagined that the creators of roadmaps and strategies could place a “Threshold line” on the diagram and use it to plan their activities: moving the threshold line up or down on the vertical scale could help in filtering the attributes and optimise between the desired maturity levels and the resources available to invest in the selected attributes.

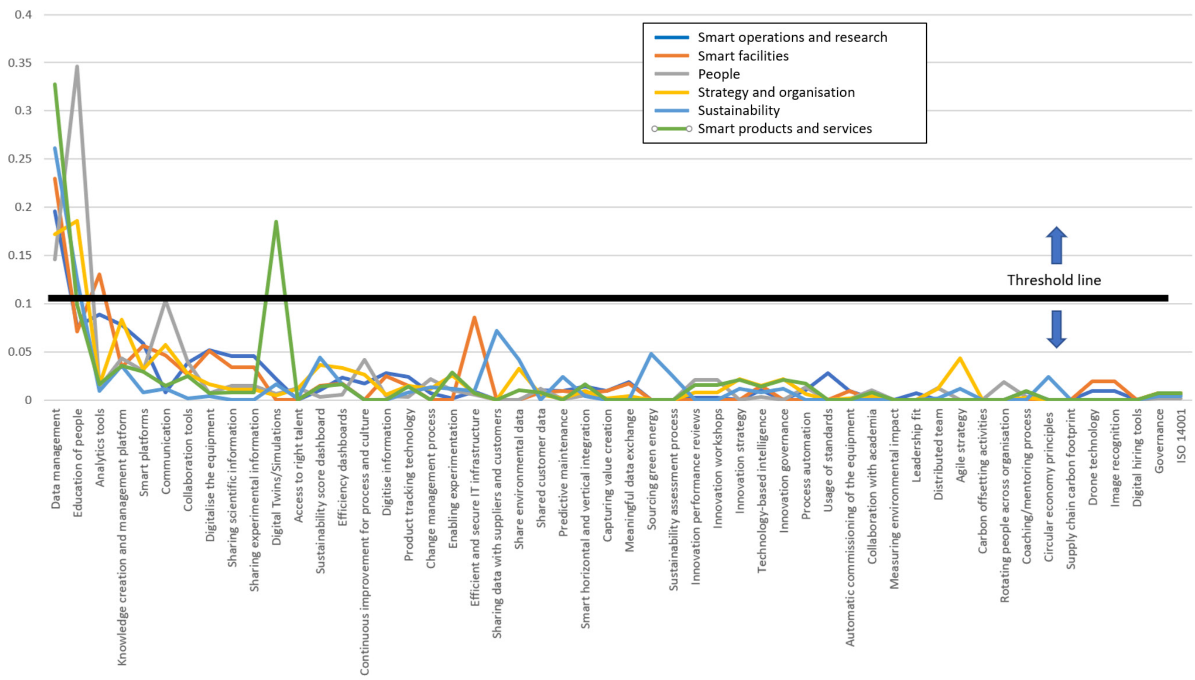

Fig. 7 Attributes’ influence on dimensions

Sustainability aspect

One of the observations after conducting the initial review was that currently available Digital Maturity or Industry 4.0 Readiness models do not include the sustainability aspect. The authors asked themselves the following question: “why is sustainability important, and should it be included in digitalisation activities at all?”

The conclusion was that it is impossible to be “digitally mature” without considering the sustainability aspect. This is true even more in the case of R&D organisations as they work to drive and secure the long-term future (and thus economic sustainability) of the company. This thinking was confirmed by the results from the interviews, where the dimension of “Sustainability” had the centrality of 0.045, placing it in third place after “Smart operations and research” and

"People" and before "Strategy and organisation", "Smart facilities" and "Smart products and services". This clearly demonstrates that it is high on the agenda of the experts. It is also natural to think that an organisation that progresses on the digital maturity journey will become more efficient, generating less waste, becoming naturally more friendly to the environment and to society. There are other, non-tangible motivations like the simple fact that people care about sustainability more than they used to years ago, knowing more about how operations impact the environment and society.

Such conclusions were also confirmed by emerging research which concludes that both digitalisation and sustainability are interconnected [8, 18, 19].

To further understand the current situation, separate interviews were conducted with both Sustainability and Digitalisation teams in one of the world's leading manufacturing companies, concluding that even if companies include both Digital and Sustainability strategies in their operations, they are most likely executed in parallel by different teams. The skills of the teams are different or hardly overlapping, with the Digitalisation teams being more technical than the Sustainability teams. Another observation was that, while there is an initial appetite to merge both concepts from the Sustainability side, the Digitalisation tends to focus on narrower aspects related to shorter-term goals associated with ongoing projects like reducing energy consumption, CO_2 emissions, diffuse dust pollution, etc.)

6. Conclusion

In this study the authors attempted to determine the key elements of the Digital Maturity model applicable to R&D organisations, including the aspect of sustainability. Using the Means-End Chain method, the authors confirmed that digitalisation and sustainability are interconnected and that, by working together, they support each other. This is in line with conclusions from other research already available, including outcomes from studies carried out by Denicolai et al. [8] and Gupta et al. [19]. With this in mind, and the fact that the "Sustainability" dimension was the third most important one by centrality after "Smart operations and research" and "People", the authors concluded that it should be included in the maturity model.

The following dimensions of the R&D Digital Maturity model emerged from the research, listed from largest to smallest centrality: "Smart operations and research", "People", "Sustainability", "Strategy and organisation", "Smart facilities" and "Smart products and services". Interestingly, looking into the centrality gap between these elements, it can be determined that "Smart operations and research" should be the most important element to address. The gap between this element and the next two ("People" and "Sustainability") was 0.019. Expert opinion clearly stated that the way in which R&D is organised, how it conducts the experiments, how it collects, stores and uses data, how it generates and shares knowledge, and the way it collaborates with both customers and partners are the key factors to accelerate research outcomes. The next areas to review when considering the digital maturity roadmap are "People" and "Sustainability". The centrality gap between them was only 0.006, which indicates that they are both of equal importance. The second highest centrality for the "People" dimension clearly indicates that culture and the people factor must be considered together with the technology factor during the setting up of the transformation program. Sustainability had the third highest centrality score, showing its growing importance. The last three dimensions, "Strategy and Organisation", "Smart Facilities" and "Smart Products and Services", were separated from the three first by 0.027. Such gap splits the dimensions into two clusters which can be used as an indication for priority when building the digital transformation roadmaps. It is possible that such distribution is specific and only visible for R&D organisations, as they usually rely on human potential enabling creativity and innovation based on the solid foundation of technology.

Collaboration between digitalisation and sustainability is essential. R&D organisations should embrace and lead this effort as they are at the forefront of progress in all industries. The authors included the aspect of sustainability in the Digital Maturity model based on the results from the interviews, but also based on emerging trends, where both strategies are at the top of the agendas of companies as well as policy-makers in the majority of countries, companies and institutions. The digitalisation will aid and accelerate the path to sustainability by the application of technologies, processes, and skills. Most likely those R&D organisations which progress on the digital maturity path and include the "Sustainability" dimension will be able to better carry out activities to innovate and introduce new products, services, and processes. They will also support their customers better and use innovative and effective ways to generate and share knowledge, which, in turn, will automatically help both their internal or external customers to become leaders in their respective markets and sectors.

When it comes to further research, the authors suggest two paths built on their initial work. Path 1 focuses on continuing to build the Digital Maturity model for R&D organisations by further nurturing the attributes and benefits leading to the model, including levels of maturity, scores and the process of assessing digital maturity, as well as the process of monitoring progress. This could result in an assessment tool that could be used by various organisations to assess their maturity and build their digital roadmaps. Path 2 relates to the Sustainability dimension to further nurture how technologies can accelerate it. It can be focused on all the aspects of digitalisation (for example, how predictive maintenance can extend the life of an asset, how a digital twin can eliminate the need for physical design, testing and monitoring, how IoT/IIoT can facilitate data science-based techniques and remote operations and monitoring, contributing towards such factors as health and safety, reducing waste and pollution and many others.

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