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Resilience compass navigation through manufacturing organization uncertainty – A dynamic capabilities approach using mixed methods

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ABSTRACT

In uncertain manufacturing environments, tools that help companies and supply chains navigate unexpected events and promote sustainability are crucial. However, the application of resilience in manufacturing organizations is limited, often focusing on supply chain resilience. This study used mixed methods to minimize subjectivity in manufacturing resilience. A quantitative Content Validity Index (CVI) helped develop the 'resilience compass' assessment tool, while empirical applications in six manufacturing organizations demonstrated its usefulness. The study identifies relationships between 54 resilience practices, 11 dynamic capabilities, and three stages: anticipation, coping, and adaptation, providing decision-makers with actionable insights to enhance manufacturing resilience.

1. Introduction

Manufacturing enterprises are susceptible to unforeseen occurrences, encompassing natural disasters, human-induced events, production interruptions, and swift technological shifts, invariably leading to disruptions. Such events can lead to economic ramifications [4] and engender adverse sustainability repercussions. Escalating demands for organizational sustainability have been propelled by contemporary constraints such as resource scarcity, repercussions of climate change, regulatory imperatives, and geopolitical tensions, among others. A new triple bottom line known as Industry 5.0 has been advocated [5,6] where advanced technologies from Industry 4.0 [7] can support value creation in systems that are human centric, sustainable, and resilient.

Resilience represents a contemporary terminological shift from prior paradigms like flexibility and agility, which were traditionally employed to address routine operational fluctuations [2]. Contrary to the original definition of resilience provided by Holling [8] for ecological systems, resilience is more than just bouncing back to normal or new functional states or reacting to unintended events. Resilience is a larger multi-dimensional umbrella concept [9], that can help organizations come out of crises stronger than before and is more forward looking. It goes beyond traditional risk management practices and should be designed or developed in organizations, rather than being a spontaneous reaction to disruptions [10].

The relationship between the different underlying factors of the resilience concept (*a theoretical entity representing resilience*) has been previously studied in the operations management field [11,12] at the organizational level [2,13] and extended to supply chains as well [14–18]. In addition, the contextual application of resilience has evolved from systems that encompass static components in steady state conditions to organizations and supply chains that contain dynamic interactions between socio-ecological actors [19]. The concept of organizational resilience [2,20] could be applied for manufacturing, however its application in a real-world manufacturing organization context is yet to be fully understood and few studies [21–25] address this. In addition, the need to build multi-capability resilience [17] and time-dependent resilience responses [14,26,27] have been advocated for supply chains in recent literature but these require empirical validation in manufacturing organizations.

Capabilities are foundational pillars of an organization's resilience and improve its performance when faced with adversities and disruptions [28]. Specifically, dynamic capabilities (DCs) [29] have been effective in making systems more resilient [30–32]. Several other theories have been proposed in supply chain resilience (SCRES) literature,

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for instance, the resource-based view (RBV), systems theory, complex adaptive systems and so on [15] and in management research such as complex systems and network theory, high reliability theory, social capital theory [12] and so on. Although resilience needs to be considered from a systems-level supply chain perspective that goes beyond individual companies, there is limited research on an 'organization's' ability to respond to unexpected supply chain risks [33] in dynamically changing environments. Therefore, we use the theoretical lens of DCs in the present study to build manufacturing resilience. Dynamic capabilities are a 'firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing circumstances' [29].

Several methods, frameworks and tools are available in the literature that measure or assess resilience. They range from theoretical [34] to empirically validated [28], based on dynamic capabilities theory [30, 35–37] or resilience practices [14,38]. However, building 'manufacturing' resilience capabilities based on concrete practices covering all temporal stages (before, during and after disruption) is missing. Resilience measurement can be subjective and highly context specific [15]. Therefore, a comprehensive method is needed that is practice-based, risk-informed, temporal, simple (intuitive and easy to use) and generalizable (not dependent on company size or manufacturing sector). The method should also consider dynamic capabilities (as resilience evolves over time) and feedback loops to learn from previous disruptive events. Given this background and the research gaps identified, this study aims to develop such a resilience assessment method for manufacturing organizations, called the resilience compass.

The paper is organized as follows: after this introduction, we present the theoretical background in Section 2. The procedures adopted to develop the assessment tool and assess it in the six manufacturing companies are presented in Section 3. This is followed by the results in Section 4 which describes the assessment tool and its application in the six companies. Section 5 discusses the results followed by Section 6 which provides the main conclusions.

2. Theoretical background

While research on resilience has been conducted across diverse disciplines, including management, ecology, sociology, engineering, supply chains, etc, there is no consensus on the definition, relationships, and measures of resilience even within these fields [13,27,39,40]. This section provides an overview of the constituent concepts comprising resilience and delineates its assessment.

2.1. Unravelling resilience terminologies

Various taxonomies delineating resilience temporal stages have been documented in the existing literature, including proactive and reactive [17,41,42]; supply-side and demand-side capabilities [43] and strategies [44]; anticipation, coping and adaptation [2]; readiness, response and recovery [13,45] and renewal [46]; pre-hazard, hazard and post-hazard [47]; fragile, robust, resilient, antfragile [39]; prevention/preparedness, detection, response, recovery [48]; absorptive, adaptive [49] and transformative [50] pathways among many others.

We also find several associated terminologies of resilience such as flexibility, agility, collaboration [28,30,45,51], redundancy strategies [52] and so on. In addition, many relationships are overlapping [15]. For instance, although flexibility can be considered as a capability for enhancing organizational resilience [28,30], Singh et al. [31] described that DCs can build the strategic flexibility in companies. In other research, ambidexterity was considered to be a capability for resilience [53,54], however, Aslam et al. [55] studied the influence of agility and adaptability on ambidexterity. Both Singh et al. [31] and Aslam et al. [55] did not explictly mention the term resilience in their research.

Some terms are also used interchangeably with the phases of resilience. For instance, adaptability and recovery were considered as capabilities for resilience [16,28], however, these were considered as temporal stages of building overall organizational resilience [2,49]. Ruiz-Martin et al. [39] connected resilience related concepts to fragilty, robustness and antifragility. However, robustness – a term often confused with resilience [14] – is defined as the ability of systems to maintain functions despite disruptive events [56] and can enhance decision making in disrupted supply networks [57].

Some common definitions of organizational resilience are provided in Table 1. They were categorised according to a temporal stage or phase of resilience. Anticipation is considered as a proactive phase [2]. Some authors call this as a readiness [45,58] or detection phase [59]. The coping [2] or response stage [45,58] follows the anticipation stage and is concurrent with short-term practices; and this is lastly followed by a reactive stage with several terminologies found in the literature such as adaptation [2], recovery [45,58] or learning [59].

Teece et al. [29] propose the interdependency of sensing (analytical systems and individual capacities to sense, filter, shape, and calibrate opportunities), of seizing (firḿs structures, procedures, design, and incentives for seizing opportunities), and of transforming (continuous alignment and realignment of specific tangible and intangible assets) DC microlevels. Transposing to the organizational resilience conceptualization, these microlevels can be related to the three resilience stages of anticipation (sensing), coping (seizing), and adaptation (transforming). The ISO 22316:2017 standard defines organizational resilience as 'the ability of an organization to absorb and adapt in a changing environment to enable it to deliver its objectives and to survive and prosper' [60]. In this study, we define resilience according to the temporal stages

Table 1
Definitions of organizational resilience from the literature.

Resilience stage	Definition from the literature	Reference
Anticipation/ Readiness/ Detection *(proactive phase)*	The ability of identifying potential risks and taking proactive steps to ensure that an organization thrives in the face of adversity.	[61]
	The incremental capacity of an organization to anticipate and adjust to the environment.	[20]
Coping/ Response *(concurrent phase)*	The capacity of organizations to cope with unanticipated dangers after they have manifested.	[62,63]
	The systemic capabilities of socio-technical systems to accommodate the effects of change stressors.	[64]
Adaptation/Learning/ Recovery *(reactive phase)*	A firm's ability to recover from supply chain disruptions quickly.	[65]
	The ability of a system to return to its original state or move to a new, more desirable state after being disturbed.	[40]
	The capacity of an organization to survive, adapt and sustain the business in the face of turbulent change.	[66]
Other overlapping definitions		
Robustness	Implies self-regulation and resistance to disturbances of a system	[67]
	The capacity of a system to tolerate disturbances while retaining its structure and function.	[68]
Anticipation and adaptation	The ability to prevent supply chain interruption and can also recover quickly back to normal operating conditions even after suffering from heavy disruptions.	[69]
Coping and adaptation	The measurable combination of characteristics, abilities, capacities, or capabilities that allows an organization to withstand known and unknown disturbances and still survive.	[39]
Anticipation, coping, and adaptation	The ability to anticipate potential threats, to cope effectively with adverse events, and to adapt to changing conditions.	[2]
	The capacity for an enterprise to survive, adapt and grow in the face of turbulent change.	[28]

described by Duchek [2] as the ability of organizations 'to anticipate potential threats, to cope effectively with adverse events, and to adapt to changing conditions'. Other definitions can also be found in Conz and Magnani [49].

2.2. Capabilities and practices for manufacturing resilience

The terminology encompassing capabilities, practices, actions, strategies, and sub-factors associated with resilience exhibits a degree of interchangeability, with diverse authors presenting varying perspectives on their systematic organization and conceptualization. To cope with this polysemy, this study uses the dynamic capability view as the theoretical background to support resilience categorization and development.

As organizational resilience is path-dependent [20,49] and represents a certain organizational ability, capacity, or capability (as indicated by the definitions in Table 1), the use of DC theory is a natural choice to support the present research. Other studies have considered DCs for the viability of supply chains [70], remanufacturing capability [69], absorptive capacity and digital organizational culture [71], and resilience as a DC to repurpose manufacturing operations [72]. Yet, few studies empirically assess organizational or specifically, manufacturing resilience according to dynamic capabilities and practices in the temporal resilience stages, as it is proposed by our research.

In the context of this study, we describe practices as the specific activities undertaken by organizations to engender particular capabilities. Capabilities, on the other hand, denote the inherent capacities that organizations must possess to facilitate the formulation of resilience strategies in the three temporal stages. These overarching strategies manifest across temporal phases, enabling organizations to proactively prepare for, respond to, recover from, and learn from disruptions [14]. Conversely, resilience strategies may necessitate the cultivation of specific capabilities [73], which, in turn, could mandate the establishment of particular organizational practices. A schematic of these relationships is found in Fig. 1. Hence, to operationalize the resilience construct (*an empirical entity representing resilience that is quantitatively measured*), and as a first step in the literature analysis, we identified capabilities that encompass manufacturing resilience. We then identified several practices that give rise to manufacturing resilience.

Han et al. [45], Ali et al. [14], Negri et al. [38] and Adobor and McMullen [74] performed systematic literature reviews and classified capabilities based on their impact on supply chain resilience (SCRE) and further details on their categorizations can be found in their work. Although financial strength was considered as a capability by Pettit et al. [28], it was categorised as a practice under the market position capability by Han et al. [45]. From our understanding, many of the derived capabilities could also give rise to another capability [75]. For instance, financial strength could give rise to sound market position. In addition, the capabilities could also be categorised under supply-side, demand-side, manufacturing or logistics capabilities.

Clearly visualizing factors such as unexpected risks, disruptions and DCs for resilience may help develop suitable resilience strategies in different stages (Fig. 2). Here, DCs and strategies have a clear distinction [59,76]. Teece [76] described the two terms as interdependent and when coupled together, they can bring about a firm's competitive advantage. Teece [76] presented DCs as unique, competitive capabilities to align the resources required to cope with dynamically changing environments and strategies as those activities that specify how the resources or assets will be deployed. In addition, resilience strategies should be timed and align with the different stages of resilience [59]. However, resilience stages in general may not be mutually exclusive [2], and the capabilities that encompass them could be interrelated [74,75].

However, there is still a lack of clarity in (a) the alignment between these capabilities and practices to DCs and the temporal stages, and (b) the development and application of a resilience assessment tool for manufacturing according to (a).

2.3. Measuring resilience levels

Resilience assessment methods should be able to demonstrate an organization's embedded capability to perform and adapt under adversity and change (i.e., what it can do) which is more meaningful than a simpler audit approach where certain processes and products are confirmed to be in place (i.e., what it has and what it does) [46].

Several resilience assessment methods such as maturity models [39,46,77], frameworks [34,78,79], scales [33,35], quantitative methods [80] and performance metrics [17,45,47], approaches that consider supplier assessments [81] and supply chain ripple effects [82–84], and so on have been proposed to measure resilience levels. However, many of these tools have not assessed resilience in the manufacturing context, along with a specification of dynamic capabilities and application of corresponding practices in the three temporal stages of resilience. For instance, Chowdhury and Quaddus [35] created a robust measurement instrument for SCRE, but the tool was missing practices in the resilience stage of learning or transformation. Faruquee et al. [17] investigated different combinations of capabilities in their typology framework, but did not address capabilities in the learning stage as well. Cheng et al. [47] propose quantitative metrics in the three resilience stages to measure production resilience where seven steps were applied to a generic semiconductor shortage case, but the metrics were purely quantitative and were not validated in a real-world empirical context.

As seen above, although the literature available on resilience assessment methods is vast for the generic organizational context as well as for supply chains, it is not available for the context of a manufacturing company. Assessment tools that work well for general organizations might not be suitable for the unique needs of manufacturing organizations. In addition, easily applicable self-assessment tools that can help manufacturing companies understand resilience capability implementation levels in their current and desired future states are missing in literature and practice. Accordingly, we place our research contribution in relation to previously developed work in Table 2.

3. Method

We used a mixed method approach in four stages to build and apply the resilience compass for manufacturing companies. For this, we first needed to develop a sound measurement instrument. A basic requirement of the developed instrument is to have sufficient content validity of

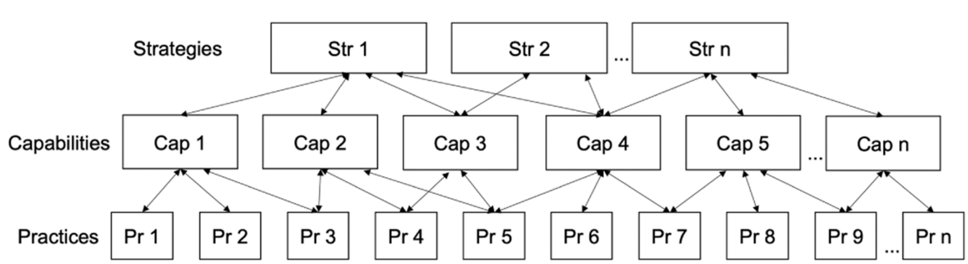

Fig. 1. Relationship between practices, capabilities, and strategies to build resilience.

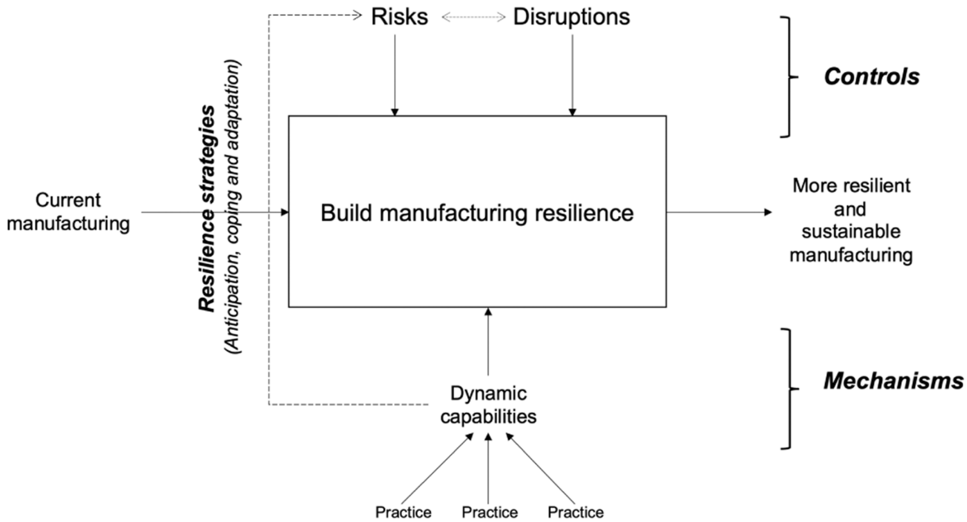

Fig. 2. Holistic resilience framework based on IDEF0
Adapted from [3].

items that have a good representation of its content [1]. The Content Validity Index (CVI) method was used to check the content relevance of items in the mesurement instrument [88]. A detailed description of the tasks and outcomes in the different stages of the measurement instrument development and application is shown in Fig. 3.

3.1. Stage 1 – development of measurement instrument

The first stage comprised the measurement instrument development requiring operational definitions and the generation of appropriate items underlying the main resilience construct [89]. Hence, this stage consisted of - conceptual and domain definitions of the construct [90], item generation to represent the contruct, pilot testing and instrument formation [1]. We started with an inductive approach, scanning literature in the Scopus database with search strings that included keywords such as resilien* , manufactur* , production, 'dynamic capabilit* ', measure* , assess* , 'organi*ational resilien* ', 'manufactur* resilien* ', 'critical success factor', 'best practice' and 'necessary condition'.

Subsequently, two distinct lists were compiled, one comprising capabilities and the other encompassing practices or sub-factors pertinent to resilience. Then, a deductive review of literature helped ascertain comprehensiveness and establish connections between the identified practices and capabilities. Following this, multiple iterations of pilot testing were conducted, involving six academic practitioners and two industrial companies, with emphasis on assessing the items' uniqueness, significance, and clarity [1] with respect to the resilience domain and their relation to the capabilities.

3.2. Stage 2 – judgement quantification

In the second stage, we assessed the content validity of practices against capabilities using the Content Validity Index (CVI) and modified kappa (k *) [91]. The number of experts required for assessing measurement instruments is contested [92,93]. The sampling criteria was based on: representation of experts from both academia and practice; and sufficient knowledge [94] in one or more areas of operations management, resilience, dynamic capabilities, and risk management. Based on this, 24 experts were contacted to perform the rating task following Grant and Davis [95]'s recommendation. This larger expert pool also minimizes chance agreement [1]. Seventeen of these experts agreed to participate and two declined due to limited expertise. The survey was distributed to the 17 participants who were given four weeks to complete it. Initially, nine responses were received. After a reminder, two more responses were obtained, totalling 11 responses.

The derived resilience practices were then distributed in the form of survey questions. Experts evaluated item representation on a 1–5 Likert scale, with a '3-neutral' option included, aligning with recommended practice [1,96]. This choice aimed to capture varying levels of agreement and prevent information loss. Ratings were categorized into content invalid (1 and 2) and content valid (4 and 5) to minimize chance agreement. We observed a dearth of similar studies for comparative analysis, thus our calculations focused on ratings of 1, 2, 4, and 5. Item retention was approached cautiously, retaining only items with less than two '3-neutral' ratings from experts. Next, for each item, we calculated the item level CVI (I-CVI) according to (1):

$$\mathrm{I-CVI} = \frac{\text{Number of experts who agreed (ratings 4 or 5)}}{\text{Total number of experts (ratings other than 3)}} \tag{1}$$

Items were retained based on criteria outlined in Table 3. The use of modified kappa (k*) as a supplement to CVI can eliminate chance agreement between raters, particularly in dichotomous relevant/non-relevant categories [91]. However, with 11 experts in our study, the need to calculate k* values for items was obviated, as the probability of chance agreement diminishes with 10 or more experts, where I-CVI becomes equivalent to k* .

3.3. Stage 3 – refinement of the measurement instrument

In addition to the two initial stages recommended in the CVI approach [92], a crucial third stage involves refining the instrument [1, 90]. In this phase, a quantitative content validity assessment of the revised 54 items (from Stage 2) was conducted through a second round of surveys. As advised by Polit et al. [91] three experts who were not involved in the initial content validity assessment (in Stage 2) [92] evaluated item alignment with the 11 constructs. Their domain expertise were in the areas of supply chain management and product development. For this stage, a 4-point Likert rating scale was employed in the survey, as recommended by Almanasreh et al. [1] without the neutral option. Data analysis followed the same I-CVI approach as in Stage 2.

Furthermore, scale-level content validity (S-CVI) was calculated to assess the overall content validity of the entire measurement instrument. The S-CVI can be determined using the average method (S-CVI/Ave), which averages the proportion of relevant items across the experts, or the universal agreement method (S-CVI/UA), defined as the proportion of items on an instrument that received a rating of 3 or 4 (valid) by all the content experts. Although Polit et al. [91] favored the S-CVI/Ave due

Table 2
Author contribution table (SLR: Systematic literature review).

Reference	Resilience assessment method	Primary outcomes achieved
Cheng et al. [47]	Seven-step resilience evaluation framework (Empirically evaluated in semiconductor case study)	Development of multimodal resilience metrics for resilience assessment and improvement
Duchek [2]	Capability-based dynamic resilience framework (SLR)	Conceptual framework developed to show that combination of capabilities in different stages along with antecedents and drivers can give rise to resilience
Zhang and Sharifi [85]	Conceptual model and methodology for implementing agility (Empirically evaluated)	Derived drivers and capabilities for agility, assessed level of implementation and effectiveness of agility providers
Han et al. [45]	Supply chain (SC) resilience capabilities performance metrics framework (SLR)	Provided trade-offs between capabilities and performance metrics for SC resilience assessment
Singh et al. [31]	DCs and flexibility constructs research framework (Empirically evaluated)	Studied the influence of six DCs on five strategic flexibility dimensions in SMEs
Somers [61]	Organizational resilience potential scale (ORPS) (Empirically evaluated)	The scale was used to measure latent resilience in organizations where level of perceived risk, information seeking, organizational structure, continuity and community planning could be determined
Edgeman et al. [86]	Sustainable enterprise excellence, resilience, robustness, and resplendence ($SEER^3$) model (Theoretical work)	The model was developed to help organizations advance their performance with respect to sustainability and resilience using visual self-assessment dashboards
Conz and Magnani [49]	Conceptual framework of resilience responses according to temporal pathways (SLR)	The conceptual framework and capabilities defined along the two temporal pathways can help firms decide which path to take as a response to shocks
Dwaikat et al. [72]	4Rs supply chain conceptual resilience framework (Empirically evaluated)	Investigated the role of four DCs for achieving production changeover
Pettit et al. [28]	Supply chain resilience assessment and management (SCRAM) tool (Empirically evaluated)	Prioritization of vulnerabilities vs capabilities were computed
Mohammed et al. [37]	Methodology that combined Multi-attribute decision making (MADM) algorithms and a multi-objective programming model	The methodology was used to evaluate the internal dynamic resilience capabilities and external supplier resilience of an organization towards SC resilience
Mohammed et al. [87]	The IRCs (Internal resilience capabilities) - PADRIC (Preparedness, Agility, Development, Recovery, Innovation and Collaboration) framework	The internal capabilities of an organization were identified using the framework and quantitatively assessed using a DEMATEL and MARCOS approach
This research	Resilience compass (Empirically evaluated in six manufacturing companies)	Assessment of manufacturing resilience through the development of DC microfoundations in the three temporal phases of resilience

to its focus on item quality rather than expert performance, Almanasreh et al. [1] suggested reporting both values as a standardised informative procedure. Hence, both the Ave-CVI and UA-CVI were calculated according to (2) and (3).

$$\text{Ave} - \text{CVI} = \frac{\text{Sum of I} - \text{CVIs}}{\text{Total number of items}} \tag{2}$$

$$\text{UA} - \text{CVI} = \frac{\text{Number of items rated 3 or 4}}{\text{Total number of items}} \tag{3}$$

3.4. Stage 4 – application of the resilience compass in the RE4DY project

The fourth and final stage entailed the application of the refined measurement instrument in the form of a resilience compass, based on a qualitative approach using six manufacturing companies based in the EU as part of the RE4DY project [97]. The project's mission is to build data-driven active resilience strategies for manufacturing and supply networks through digital continuity and sovereign data spaces across all product and process lifecycle phases. The project comprised four use cases of six companies in the automotive, aeronautics, e-battery and machine tool domains (Table 4). The specific manufacturing companies discussed in this study were pertinent to the research's focus on developing and assessing a resilience measurement tool against the identified theoretical resilience concepts. The study's theoretical domain was confined to the manufacturing firm level, and the selected use cases were deliberately chosen within this domain, emphasizing the study's targeted nature.

Company A comprises an automotive assembly plant, with the objective of improving the quality and cost of the logistics department. Company B offers innovative aeronautical solutions for civil and military sectors. Use cases 3 and 4 comprise a supplier and a client each to enable collaborative ecosystems. Company C provides highly customized production systems of e-battery packages to Company D who focuses on e-mobility in cars. Company E is a high precision milling machining tool manufacturer providing solutions to Company F, a leading manufacturer of machining tool device and automation systems.

The initial expectations from the companies for the need of a resilience framework (as the assessment tool was first defined) was that it should 'create the conditions for adaptable logistics ecosystems that are resilient to external and internal factors linked to the automotive industry.' (Company A), and 'ensure that any kind of disruption can be recovered in the most efficient way minimizing the negative impacts on the processes and contain solutions that allow production machines to expose data in a digital format on which business strategies can be based' (Company B). Recent history has shown a great uncertainty about the future of the automotive industry i.e., power train technologies. Company B mentioned that this key factor brings punishing complexity with the integration of new production/logistics processes for new power train technologies in brown field plants, all the while maintaining acceptable profit margins and respecting ethical, political and environmental missions', making resilience an important aspect to incorporate into strategic decision making.

In addition, the resilience framework should 'support digital continuity that allows integration of different vendors independent of disruptive events, continuous updating of goals and gaps (current state analysis), be adaptable to existing technologies and processes where risk identification and capability improvement could easily be integrated for benchmarking now and in the future (gaps) and showcased to other engineering service providers' (Companies C and D), and 'generate processes and workflows that run stably on different hardware and software platforms, are easy to adapt, are characterized by a high degree of standards, and function in a process-safe manner for our customers' (Companies E and F).

Data was collected from the six companies between September and October 2023. First, two workshops were conducted in each of the companies, to provide clarity on the concepts and help them confidently perform self-assessments of resilience capability implementation levels. The companies were asked to assess the level of both, their existing capabilities and their desired future capabilities using a Likert scale (0 =not ready to implement to 5 =always exists). Donut graphs were then used to create the compass. Lastly, focused interviews [98] of 90 min each were conducted to understand how the companies would

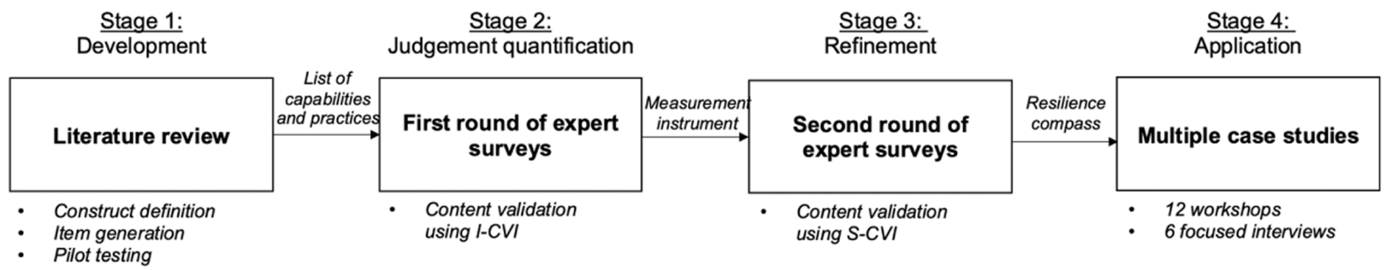

Fig. 3. Research process (First three stages based on Almanasreh et al. [1]).

Table 3
Item retention rules.

I-CVI	Comment	Number of items
> 0.7	Retain	35
> 0.7 and < 3 neutral ratings	Revise and retain	4
< 0.7 and > 3 neutral ratings	Eliminate	7
0.6 –0.7	Revise and retain	4
< 0.5	Eliminate	12

Table 4
Profile of companies in the multi-case study.

Use case description	Domain	Company/ies	No. of employees	Profile of participants
1. Connected resilient logistics design and planning	Automotive production plant	A	6000	(i) Logistics planning specialist (ii) Innovation management specialist
2. Cooperative multi-plant turbine protection with predictive quality value chains	Aeronautics	B	5500	(i) Technical product manager (ii) Team leader (R&D)
3. Collaborative ecosystem for e-batteries	E-batteries	C, D	1000 11500	(i) Team leader (R&D) (ii) Senior project manager (R&D)
4. Collaborative ecosystem integrated machine tool performance self-optimization	Machine tool	E, F	550 3300	(i) CTO (ii) Project leader

use the results from the assessments.

4. Results

The resilience compass was created to provide companies with a sense of direction on where they are now and where they aspire to be in terms of resilience DC implementation, much like a compass is used as a navigational aid. The compass was based on the refined measurement instrument that encompassed the DCs and practices for resilience under the three resilience stages of anticipation, coping and adaptation (and connected to the DC microlevels of sensing, seizing and transforming) (Fig. 4). The dark coloured bands under each capability indicated the average score from the bundle of practices implemented and the dashed band indicated the maximum score chosen under that capability, for the

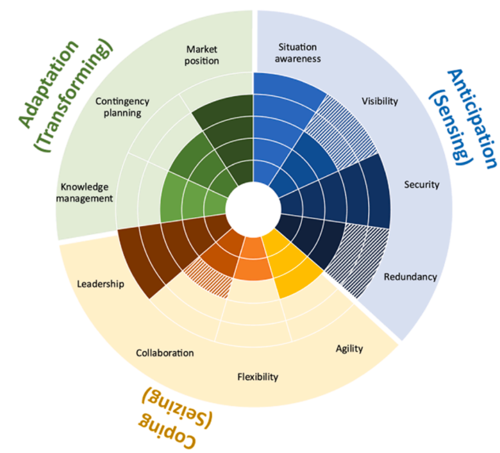

Fig. 4. The resilience compass with DC implementation levels in three resilience stages of anticipation, coping and adaptation.

current state analysis. It was more relevant to analyse resilience at the level of DCs and not for each individual practice. Hence, the scores from the practices under each capability were averaged to get the total score under each capability.

4.1. The capabilities and practices in the resilience compass

After reviewing the different capability categorizations found in the literature, we adopted the capabilities and resilience temporal stages' description according to Duchek [2] and Han et al. [45] to employ in the resilience compass. Duchek [2]'s work investigated resilience capabilities in the anticipation, coping and adaptation stages, while Han et al. [45] described them as readiness, response and recovery stages. We chose to be consistent with the resilience stage terminologies as prescribed by Duchek [2]. For instance, the term anticipation better describes the detection or scanning of surrounding environments [13], where organizations can 'see' critical threats or developments and potentially minimize negative impacts [99]. The coping stage involves dealing with unexpected events (an organization's response) where organizations must accept problems and then develop and implement necessary solutions [2]. The capabilities that fall under this stage imply short-term actions to deal with disruptions [99]. The adaptation stage involves the ability to adjust after a disruption or crisis has occurred (an organization's recovery) and develop life-long learning within the organization [2,100]. These stages were found to be synonymous to the 'sensing', 'seizing' and 'transforming' DC microlevels as proposed by Teece [101], under which the DCs are classified as 'microfoundations' (Fig. 5). For the sake of ease of representation, these DC microfoundations are simply called DCs in this paper.

As previously described, the underlying DCs cannot be strictly categorised under the three stages. For instance, in order to accept risks and system failures, one must understand the surrounding environment in which systems operate – an activity also part of the anticipation stage

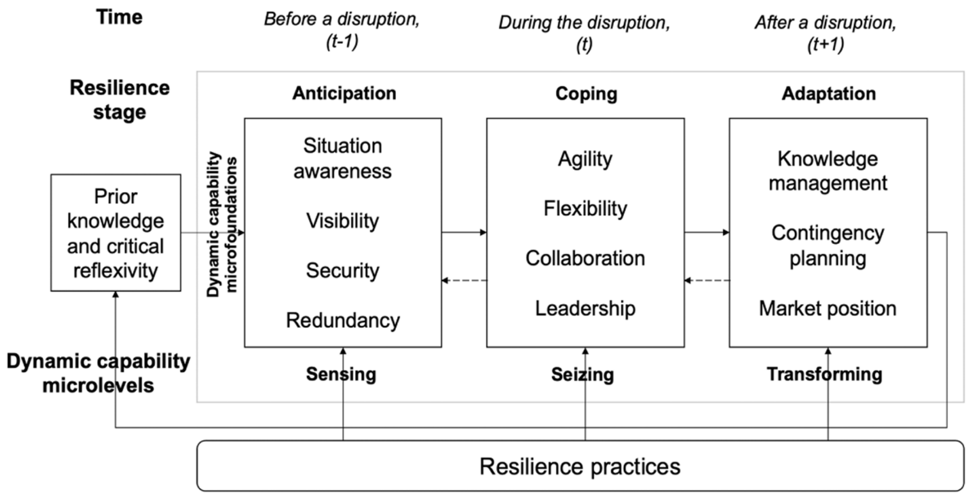

Fig. 5. A dynamic capability-based conceptualization of manufacturing resilience
Adapted from [2].

[2]. Knowledge management can be developed in the pre-disruption stage through practices such as simulations, exercises, drills and inter-organizational learning as well as in the adaptation stage through innovation in contingency planning, becoming a learning organization, feedback, etc [14]. Facilitating solutions in the coping stage also involves a certain level of creativity – a process known as bricolage [102], which allows organizations to improvise and activate informal, complementary ad-hoc solutions that dissolve once the disruptions disappear.

4.2. Item (practice) retention

Eleven dynamic capabilities (constructs) and 62 practices (items) were identified after Stage 2 in the development of the measurement instrument. First, the I-CVI of these 62 items was calculated as described under Stage 3 (Table A2 in the Appendix). Next, 43 of these 62 items were retained or accepted according to the rules described in Table 3.

The item 'we can re-purpose our facilities to help other companies when needed' which was initially categorised under 'contingency planning' was moved to 'flexibility' as suggested by one expert and rephrased as 'we can re-purpose our facilities to create alternative products in times of need'. Eleven practices were suggested to be added by the experts in the first round (Table 5), giving rise to 54 practices that were finally retained for further instrument refinement.

The S-CVI/Ave and S-CVI/UA of the 54 revised items in the measurement instrument were 0.9 and 0.7, considered adequate for accepting the measurement instrument [1]. These 11 DCs and 54 practices were then considered to be a part of the revised measurement instrument, which was used to develop the resilience compass for self-assessment by the companies (using Excel).

Hence, 11 DCs (taken from [45]) were consolidated into the three time-dependent resilience stages of anticipation, coping and recovery, along with antecedents such as prior knowledge [2] and critical reflexivity [100] which need to be continuously applied while building and applying the capabilities (Fig. 5); and 54 organizational practices that strengthen the capabilities. The definitions of the 11 capabilities are taken from [45,103].

Table 5
Eleven additional practices suggested by experts.

Capability	Practice
Situation awareness	We conduct knowledge acquisition activities to detect threats (e.g., market research, end-user surveys, use of gatekeepers, scenario planning etc)
	We have coopetition strategies in place
Flexibility	We have reshoring strategies in place to accommodate unexpected customer demands
Collaboration	We create strategic alliances with other companies
	We have coopetition strategies in place (cooperating with a competitor to achieve a common goal)
Leadership	The management regularly conducts listening sessions/ forums for employee feedback
	Leaders across the organization engage in scenario planning exercises
	We have sustainable logistics strategies in our organization
	We effectively communicate within all levels of the organization
Knowledge management	We conduct multi-skill training of new employees to avoid quick turnover rates
	We have coopetition strategies in place (cooperating with a competitor to achieve a common goal)

4.3. Capabilities in the anticipation stage

Resilient manufacturing companies should have the ability to quickly identify potential threats and corresponding occurences of disruptions, which eventually affects how the organization will respond to mitigate such risks and recover [59]. Such anticipatory capabilities can help develop the resilience potential of organizations (prepatory capabilities before disruptions occur). This stage contains four capabilities [45] – situation awareness, visibility, security and redundancy.

4.4. Capabilities in the coping stage

Reacting to and coping with dynamically changing demands and market conditions requires organizations to rapidly reconfigure their systems as needed [59]. This stage contains four capabilities [45] – agility, flexibility, collaboration and leadership. The capabilities in this stage can also help realize resilience potential so that organizations can effectively respond to crisis situations.

4.5. Capabilities in the adaptation stage

This is a reactive stage that consists of three capabilities – knowledge management, contingency planning and market position. This last stage of building resilience is related to the ability of predictive disturbance handling and learning from previous experiences [59].

Security, leadership and knowledge management capabilities were originally left out by Han et al. [45] in their SCRE Capability Performance Metrics Framework because they could not identify corresponding performance metrics for SCRE. However, we included these capabilities as they are important in manufacturing resilience building [75].

4.6. Application of the resilience compass

The resilience compass was applied in the six manufacturing companies in the RE4DY project to understand their current (as-is) and future (to-be) states in resilience capability implementation. Fig. 6 shows the compasses for the six companies. The intent behind employing the resilience compass across the companies was not to juxtapose the assessment results among the companies. Instead, its purpose was to collect insights into the essence and progression of each company's resilience capabilities, and to gauge their readiness in managing disruptive events. Companies C-F aimed to enhance collaboration for better digital continuity, efficiency, and product utilization. This would bolster their understanding of how capability implementations collectively impact resilience. Specifically, companies C and D wanted to expedite system reconfiguration and reduce time to market. Companies E and F wanted to enhance predictive maintenance and product customization through increased data collection.

Dynamic capabilities provided an opportunity for the companies to focus on those areas that required further development (if they required to do so) to deal with certain risks. The dots represent a difference between the current and future state DC implementation levels in the companies. Three thresholds were visualised: green with < 0.5 difference, orange with < 1 difference and red with > 1 difference between the two states.

Practices such as reshoring and re-purposing facilities under the flexibility capability were not applicable in Company A as this use case involved an automotive production facility at the plant level, with statements from them such as 'The automotive industry is extremely rigid and complex. This is highly unlikely to be carried out on a short to medium term' and 'Such strategies are highly unlikely to happen. Usually when there are spikes in demand, the main focus is to help the supplier to meet that demand by investing or optimizing its production process'. Company B had high situation awareness and security capability levels: 'Risks impacting the organization can have a direct connection with the safety of the product and the activities are mandated by aviation regulatory bodies'.

Company C had good security capability, but on an average, rated themselves at a lower level for situation awareness and visibility. However, they had higher desired levels of implementation in the latter capabilities, indicating possibility for future implementation and growth (marked with a red dot). A rating of 2 (exists to some extent) was given for the practice 'We check upcoming regulations by governmental organizations' in their current state of situation awareness capability, with an aspiration to move to a level of 5 (always exists): 'From a machine builder point of view, the branch is conservative, and changes are long-term'. Company D on the other hand had similar capability levels for security and visibility, but a higher implementation level of the situation awareness capability. In terms of the contingency planning capability, Company D described that the encompassing practices were 'not a part of our main business' (level 1 was chosen). However, they described a potential to develop these capabilities if required. Additional details of the resilience assessments will be documented in Deliverable 2.3 of the RE4DY project which will be available in 2024.

5. Discussion

The work presented in this paper had three objectives: (i) Develop a resilience assessment tool at the manufacturing organization level, using a mixed methods approach to minimise the subjectivity of resilience; (ii) Operationalize manufacturing resilience using the assessment tool consisting of concrete practices, capabilities, and three time-dependent resilience stages; and (iii) Use firm-level dynamic capabilities theory to determine its connectedness to the resilience temporal stages.

This paper provided a structured way for building manufacturing resilience: the relationship of resilience DCs to the specific concrete practices, and the implementation of capabilities in the temporal stages of resilience. The resilience compass can support manufacturing companies to comprehend resilience implementation levels in their current and future states in an easy-to-understand manner. The power of early risk detection (both from an academic and practitioner point of view) puts a larger distance between manufacturing companies and disruptions that could arise due to such unintended events, which requires resilience DC development in the resilience temporal stages of anticipation, coping and adaptation. The stages, however, are non-linear and can continuously evolve as organizations learn to strengthen their resilience according to different contexts and organizational goals.

5.1. Theoretical implications

As evident from the conceptualization of resilience, the terminologies associated with it are interpreted divergently in both literature and practical applications, more so within manufacturing. This interdependency or overlap between capabilities, practices and sub-factors of resilience is due to its inherently complex nature. However, their organization in relation to the temporal stages of resilience and in turn dynamic capability microlevels especially for the manufacturing context was found to be missing. Fisher and Aguinis [104] discuss that theory advancement can occur through empirical conceptualizations which contrast, specify or structure theoretical constructs and relations. The present study contributed to theory building where complex relationships between the resilience variables (practices, capabilities and stages) were developed [105] and structured (Fig. 5, showing a dynamic capabilities-based conceptualization of manufacturing resilience). Specifically, manufacturing companies can develop capabilities 'now' and 'in the future'. Moreover, the study used the dynamic capability theory from the strategy management field and applied it in the context of production and operations management. Particularly, a measurement instrument where these practices were quantitatively validated against the capabilities and empirically assessed in different domains was found to be missing in literature and practice. All time-dependent resilience stages need to be considered if manufacturing companies want to build their resilience (a generalizable aspect of this research). However, not all the practices and capabilities may be necessary to be resilient (and they may not also be generalizable for all manufacturing domains) [106].

The study primarily contributed to theory refinement [107] where six manufacturing companies were employed to elaborate upon the underlying logic between the relationships previously developed (the application of the resilience compass as shown in Fig. 6). The resilience compass contributes to previously developed resilience assessment methods at the policy level [44,108]. For instance, the resilience compass developed by the World Economic Forum [44] consists of eight supply and demand-side dimensions and was developed using empirical data from manufacturing supply chains. However, the tool itself lacked a comprehensive set of capabilities to build resilience (other than supply and demand-side capabilities), the concrete practices under each dimension that could build resilience and the time-dependent stages under which these capabilities could be developed and visualized at a manufacturing organizational level. The resilience dashboard developed by the European Commission [108] considers crucial 'capacities' for EU countries to cope with disruptions and features that make them 'vulnerable'. However, the dashboard itself was created at a generic country-wide level and may not necessarily be applicable for manufacturing organizations.

5.2. Practical implications

The resilience compass provides recommendations to improve manufacturing resilience by making explicit which practices and DCs need to be developed in each time-dependent resilience stage. These

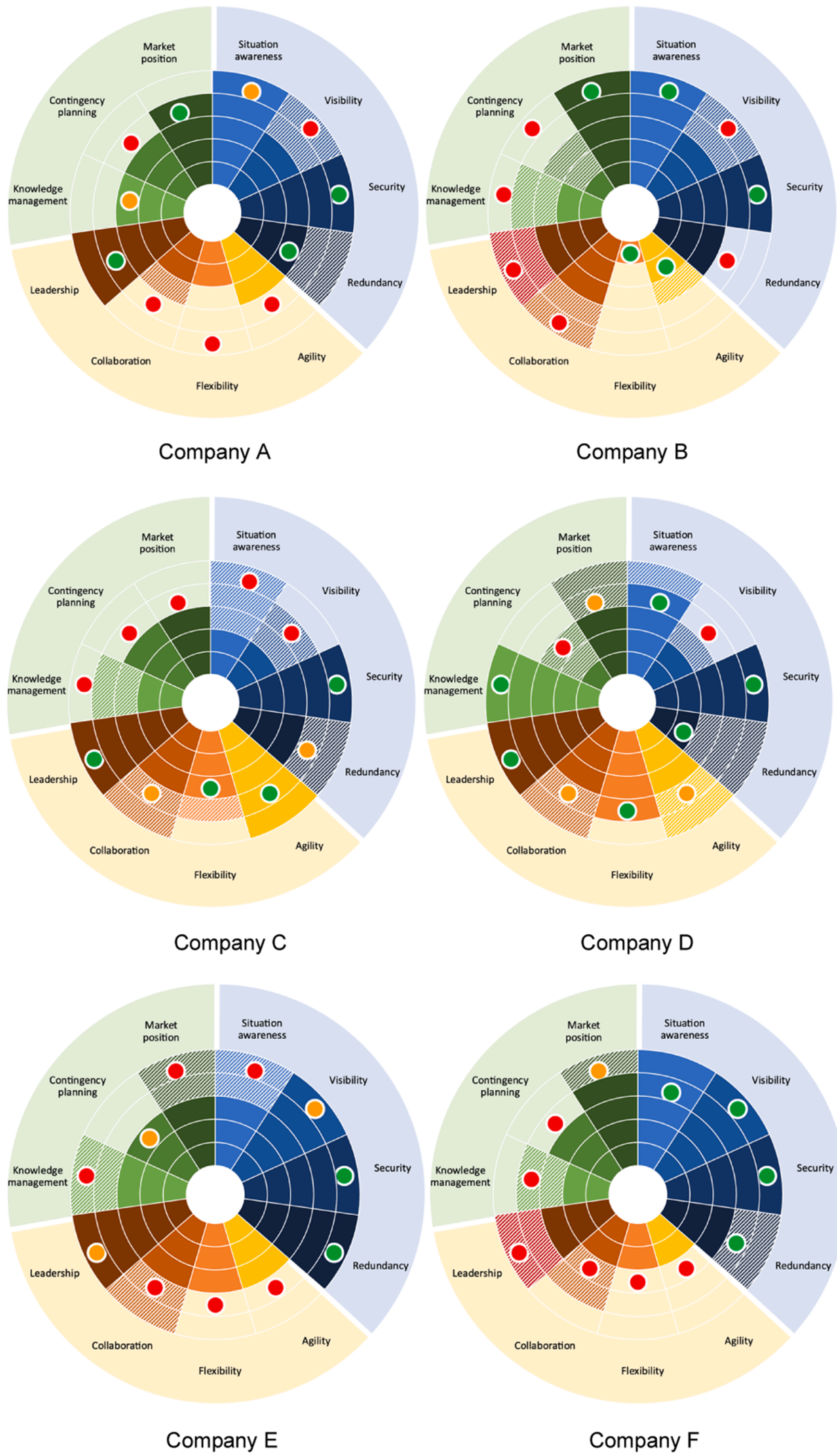

Fig. 6. Resilience compasses for the six manufacturing companies in the RE4DY project.

were then embodied into a tool to help practitioners understand and visualize manufacturing resilience from a systems perspective. The resilience compass initiates ideas that could support strategic decision making in terms of priorities for manufacturing resource investments. In addition, since average scores were calculated for the bundles of practices under each capability in the compass, manufacturing companies have an opportunity to modify the practices under each capability and make the compass relevant for their operations.

The tool resonated with the six companies who assessed their business and provided an opportunity to spark discussions with other functions in the organization, thus creating improvement ideas in their day-day operations. In terms of the value derived from doing such an assessment using the compass, Company A mentioned that it provided 'innovation and digitalization value', thus preparing the company to be 'resilient in a VUCA world' [109]. They expressed that it was possible to 'use the results in projects from different departments as well as present the compass to the entire board of directors'. They also mentioned that they could apply the tool in other functional areas of the company. Company B mentioned that they could 'extend the tool to a broader community within the company and convey the message to colleagues in the head office'. There were also possibilities to 'level up to conversations at the EU level, along with a 360 vision with the positioning of resilience and more awareness at the global level'.

Companies C and D jointly considered the value of using the compass in the e-mobility domain. For instance, they mentioned that it can help them integrate their vision with strategy or long-term development, market what-if scenarios, understand what strategies need to be developed in the different capabilities and that the transformation of industry from internal combustion to e-mobility is possible in the future. In terms of short-term benefits, they expressed that highly efficient prototyping (in the form of Manufacturing-as-a-Service) and finding new solutions were possible which would show how to improve in terms of resilience strategies to be developed. In addition, the compass will depend on the type of business delved into and accordingly, different competencies will need to be developed. The correlation between capabilities would help them make better investment decisions. The companies considered the use of digital product passports to transition towards the circular economy and enable the sustainability for different products where data is available across value chain partners. The compass would then enable an assessment of trade-offs with costs, security, reliability, and quality of data in terms of resilience for this sustainable transition. Companies E and F expressed that the compass would help them set priorities and understand any lagging indicators between their current and future states (where the largest gaps lie) from a strategic perspective.

All six companies expressed the importance of automation to build resilience capabilities in the anticipation stage. They were willing to invest in Industry 4.0 technologies to improve their capabilities in this stage as they found it to be the most relevant for building manufacturing resilience. Faruquee et al. [17] on the other hand, propose that reactive (coping) capabilities could be more useful initially for supply chains than the proactive ones. This needs empirical testing in future work by incorporating critical actors in the manufacturing value chain.

The highest level of 5 under each capability may not be important to build manufacturing resilience. Lower levels in some of the companies assessed in this study meant that they were satisfied with their resilience capability implementation levels to deal with risks and disruptions or were not willing to invest in resources to further improve their resilience levels now and in the near future. However, the implications of building a higher resilience (larger coverage in the compass) in manufacturing companies is that they may have a higher safety buffer to be less vulnerable and provides more time to respond to unintended events. This could lead to fewer costs to deal with risks and higher performance.

5.3. Limitations and future work

The choice of CVI for the data analysis presupposed that the resilience practices fell under a certain DC category based on expert opinions and previous knowledge of the authors. The size and domain expertise of the expert sample considered may have also impacted the retention of resilience practices. In addition, the list of practices was not exhaustive: the study's main goal was to demonstrate the value of identifying appropriate resilience practices that could be quantitatively evaluated against the 11 capabilities identified in the literature and comprehend how those practices could be categorized within the three stages of resilience and connected to the DC microlevels. Factor analysis to group items and create clusters of DCs can be performed in future work to provide nomenclature to the DCs.

The measurement tool was applied in a specific geographical context, i.e., manufacturing companies in Europe, and further validations are required in other geographical locations to showcase generalizability of the results. Additionally, it was tested only in discrete manufacturing companies, and will need to be tested in the service or process industry in the future.

Sharing critical information is vital for building the agility and flexibility of business processes [110] not only in the coping stage but also in the adaptation stage of resilience. This can be enabled through enterprise integration, which can be defined as the ability 'to integrate a variety of different system functionailites' [111] that are both technical and behavioral. Ontology-driven systems may help map out an ecosystem of knowledge [112] which can be particularly useful when rapid responses are required for unpredictable events that are beyond normal expectations and can have severe consequences. Future research will consider the design of ontology systems that can support interconnected knowledge graphs, thus easing decision makers' involvement in risk evaluation, resilience assessment and learning.

Some authors describe some capabilities as necessary but not sufficient for the development of organizational resilience such as anticipation [2] and robustness [58]. Yin and Ran [113] further proclaimed that no necessary conditions exist for achieving high supply chain resilience. Hence, a necessary condition analysis (NCA) [114] can be explored, to further check which conditions are 'required' for resilience. Multicriteria tools [115] could be adopted to evaluate which group of capabilities are more suitable for the development of manufacturing resilience. Mithani et al. [116] concluded that spatial proximity to threats increases an organization's probability of deploying 'slack' resources and their capacity to learn after disruptions occur. Future efforts will integrate radar-based risk management with the resilience compass to develop a resilience dashboard. This will help decision makers in planning and deploying the right capabilities to deal with different types of risks [117].

6. Conclusions

This paper advances our understanding of resilience in manufacturing companies that are exposed to risks. The research addresses a critical gap in the literature by conceptualizing manufacturing resilience through the innovative lens of dynamic capabilities and operationalizing manufacturing resilience through a resilience compass as a practical assessment tool. To minimise subjectivity with regards to resilience conceptualization, the authors used a mixed method approach combining quantitative Content Validity Index (CVI) analysis to develop the tool with an empirical application in six manufacturing companies to demonstrate generalizability. The tool provides a view of 11 DCs and 54 practices in three time-dependent resilience stages (anticipation, coping, and adaptation) that may be useful for both scholars and practitioners in manufacturing companies. The inclusion of explicit practices for dynamic capability development accounts for both present and future states.

The development of the tool was intended to translate the multidimensionality of the resilience construct into something easily accessible for manufacturing organizations and as a viable starting point to build manufacturing resilience. This paper serves as a foundation for advancing the application of resilience in manufacturing, offering a nuanced understanding of dynamic capabilities, and providing decision makers with actionable insights to plan for and build manufacturing resilience. The structured conceptualization and assessment tool presented in this paper pave the way for further research and application in the dynamic and challenging landscape of manufacturing in uncertain environments.

CRediT authorship contribution statement

Arpita Chari: Writing – original draft, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Mélanie Despeisse:** Writing – review & editing, Visualization, Validation, Supervision, Formal analysis. **Björn Johansson:** Supervision, Project administration, Funding acquisition, Formal analysis. **Sandra Morioka:** Writing – review & editing, Methodology. **Cláudia Gohr:** Writing – review & editing, Methodology. **Johan Stahre:** Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A1
Initial list of resilient constructs and items.

Dynamic capabilities (Constructs)	Practices (Items)
SA - Situation awareness	1. We conduct regular risk assessments to be vigilant to risks that impact our organization
	2. We conduct regular risk assessments to be vigilant to risks that impact our supply chain
	3. We check upcoming regulations by governmental organizations
	4. We check upcoming initiatives by non-governmental organizations (e.g., The UN, World Economic Forum, Ellen MacArthur Foundation, etc)
VI - Visibility	1. We are aware of ’where’ disruptions occur in our organization (disruptions are those that halt or change operations in a department, product life cycle stage, etc)
	2. We are aware of ’where’ disruptions occur in our supply chain
	3. We monitor our production to meet customer quality requirements
	4. We digitally track where products are located in our operations
	5. We digitally track which processes have been carried out on products
	6. We understand what data to capture across the organization’s different functions
	7. We know how data is shared within the company, thus avoiding ’information silos’
SE - Security	1. We have cyber-security measures in place
	2. We place emphasis on the quality of the working environment for our employees (e.g., no gender discrimination, focus on mental and physical health, safety, employee benefits, etc)
	3. We restrict the access of data at different levels in the organization
	4. We regularly conduct security audits in our organization
RE - Redundancy	1. We have a safety stock of ’critical’ components
	2. We can accumulate a back-up inventory in case of emergencies
	3. We have a diverse supplier base (e.g., dual-sourcing, back-up suppliers, geographically dispersed suppliers, etc)
	4. We have a diverse customer base
	5. We geographically disperse our production capacity in different sites
AG - Agility	1. We spend less time designing new solutions by using innovative technologies (e.g., automation, simulation and virtual tools)
	2. We spend less time to adapt to product changes (e.g., using special items from existing articles)
	3. We can build fire-fighting capabilities when needed
	4. We can quickly respond to disruptions without structural changes in the organization
	5. We can reduce time to market
	6. We adhere to due dates (lead time) in order fulfilment
FL - Flexibility	1. We can quickly implement a wide range of changes within existing parameter configurations
	2. It is important for us to choose green suppliers (e.g., in terms of ethical sourcing, social norms compliance, lower emissions)
	3. We audit our supplier selection process
	4. We adhere to due dates (lead time) despite complexity of product/procedures
CO - Collaboration	1. The organization works harmoniously with cross functional departments (e.g., for data sharing, knowledge transfer activities, collaborative tasks, etc)
	2. We have good relationships with our suppliers
	3. We share operational information externally with suppliers
	4. Logistics databases are integrated across the supply chain for autonomous planning
	5. It is important for us to share knowledge with our customers
	6. We have technical infrastructure (digital platforms, etc) to enable collaboration between supply chain partners
LE - Leadership	1. We decentralize strategic decisions (distributed throughout the company)
	2. We have long-term strategies in place to ’prevent’ disruptions from occurring
	3. We have sound leadership support from motivated top-level management
	4. We engage our staff in continuous improvement processes

(*continued on next page*)

Table A1 (*continued*)

Dynamic capabilities (Constructs)	Practices (Items)
	5. We implement circular economy practices (reduce, recycle, refuse, rethink, refurbish, repurpose, redesign, repair, recover, remanufacture, redistribute, etc)
	6. We employ lean production practices (e.g., minimal waste due to unneeded operations, inefficient operations, or excessive buffering in operations: optimizing process flow)
	7. We have reward systems that create a safe environment to escalate and address issues
	8. Our organization is in the process of digital transformation
KM - Knowledge management	1. We can return to steady-state conditions after a disruption has occurred
	2. We conduct knowledge empowerment training workshops for the upskilling/reskilling of our employees
	3. We leverage the use of data analytics tools (e.g., ML/AI) to train our operators
	4. We continuously learn after a disruption occurs (e.g., through information collection, verification, storage, dissemination)
	5. We employ methods to help machines understand and process data (e.g., data mining, AI, natural language processing, etc)
	6. We capture all relevant data needed to maintain our operations (e.g., system data or the transfer of tacit knowledge from operators to make it more implicit)
	7. We assess our Business Model in terms of innovative value offerings (what and how we offer value to customers)
CP - Contingency planning	1. We have scenario planning practices to think of different futures (e.g., order books that can be applied in different industries, etc)
	2. We stress test our system with disruptions to identify system configurations that result in lowest degradation and fastest recovery
	3. We can re-purpose our facilities to help other companies when needed
	4. We have supply chain integration strategies (e.g., develop common infrastructure solutions, create end-end connection with suppliers for combined decision making, knowledge creation)
	5. We design our production so that it can cope with different unpredictable events
MP - Market position	1. We have transparency on financial health across the end-to-end value chain
	2. We have quality-based performance measures in terms of costs related to product quality (after delivery)
	3. We have quality-based performance measures in terms of costs related to internal failure costs (before delivery)
	4. We monitor our environmental performance using Key Performance Indicators (KPIs)
	5. We have adequate financial support to carry out our operations
	6. We provide goods/services at reasonable costs according to customer requirements

Table A2
Descriptive statistics and CVI analysis of the variables [62 items (practices)] rated by the 11 experts. Since items were rated against a construct, the first column of the table contains combined codes according to the items and constructs labelled in Table A1.

Codes	Mean	SD	I-CVI	Accept?
SA1	4.4545	0.5222	1	Y
SA2	4.4545	0.5222	1	Y
SA3	4.1818	0.9816	0.9	Y
SA4	3.8182	1.2505	0.72	Y
VI1	3.9091	0.5394	1	Y
VI2	3.9091	1.1362	0.85	Y
VI3	3.2727	1.0090	0.6	N
VI4	3.6364	1.2060	0.7	Y
VI5	4.0909	0.8312	0.9	Y
VI6	3.9091	1.1362	0.8	Y
VI7	3.7273	1.2721	0.7	Y
SE1	4.3636	0.6742	1	Y
SE2	3.5455	1.3685	0.7	Y
SE3	3.2727	1.1037	0.6	Revise
SE4	4.0909	1.0445	0.89	Y
RE1	4.0000	1.2649	0.78	Y
RE2	3.5455	1.0357	0.75	Y
RE3	4.0000	1.1832	0.8	Y
RE4	3.4545	1.3685	0.78	Y
RE5	3.9091	1.5136	0.72	Y
AG1	3.0000	1.3416	0.56	N
AG2	4.0000	1.1832	0.8	Y
AG3	3.0909	1.2210	0.56	N
AG4	4.0909	0.7006	1	Y
AG5	2.2727	0.9045	0.12	N
AG6	3.5455	1.4397	0.67	Revise
FL1	4.2727	0.6467	1	Y
FL2	2.3636	1.2060	0.3	N
FL3	2.7273	1.1909	0.33	N
FL4	2.9091	1.1362	0.43	N
CO1	4.0000	1.0000	0.89	Y
CO2	3.5455	1.2933	0.62	N
CO3	3.8182	1.1677	0.78	Y*
CO4	3.8182	0.8739	0.89	Y
CO5	4.0000	1.0000	0.89	Y
CO6	4.0909	1.0445	0.89	Y
LE1	2.9091	1.2210	0.44	N
LE2	3.0000	1.2649	0.6	N
LE3	4.1818	0.6030	1	Y

(*continued on next page*)

Table A2 (*continued*)

LE4	4.0000	1.2649	0.89	Y
LE5	3.8182	0.8739	0.89	Y
LE6	3.0000	1.2649	0.6	N
LE7	2.5455	1.2933	0.29	N
LE8	2.7273	1.4206	0.33	N
KM1	2.6364	1.4334	0.4	N
KM2	3.5455	1.1282	0.7	Y
KM3	3.3636	1.0269	0.67	N
KM4	4.1818	0.9816	0.9	Y
KM5	3.8182	1.1677	0.78	Y
KM6	2.9091	0.9439	0.5	N
KM7	3.2727	1.1037	0.6	Revise
CP1	4.0000	1.1832	0.9	Y
CP2	4.0909	0.9439	0.9	Y
CP3	4.0000	0.7746	1	Y
CP4	3.6364	1.2863	0.78	Y
CP5	4.0000	0.7746	1	Y
MP1	3.7273	1.1909	0.75	Y
MP2	3.4545	1.1282	0.78	Y
MP3	3.0909	1.2210	0.67	Revise
MP4	3.2727	1.0090	0.62	N
MP5	2.9091	1.2210	0.5	N
MP6	3.2727	1.0090	0.62	N

Data availability

The data that support the findings of this study are available on request from the corresponding author, A.C. The data are not publicly available yet as the project deliverable will be published in 2024 and could currently compromise the privacy of the research participants.

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