Robustness, Resilience: typology of definitions through a multidisciplinary structured analysis of the literature

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Abstract: The concepts of robustness and resilience are used with increasing frequency from different sectors. The literature review reveals several meanings for each of these terms due probably to specific use in each of the sectors and a progressive adjustment of the definitions across the time. The aims of this article are to identify these definitions and the main similarities and difference between the concepts of resilience and robustness and to propose a classification of them in order to avoid confusions, bad meaning and to provide a better understanding of the subtleties under these concepts. Based on a structured analysis of the literature published in journals of different sectors this paper conceptualises and comprehensively presents a systematic review of the recent literature on robustness and resilience definitions. Decision makers and researchers can benefit from our survey since it introduces a structured analysis and recommendations as to which definitions can be used.

Keywords: structured literature review; definitions; resilience; robustness.

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1 Introduction

Nowadays robustness and resilience are popular terms often used in association with several menacing events which may induce dramatic situations (terrorist attacks, ecological crisis, natural disaster, ...). The overall robustness and resilience of modern societies is largely dependent on their management capacities of critical structures such as energy grids, transportation systems, governmental bodies or water supply (Jovanovic et al., 2016). Many research works were published on this topic and propose various indicators such as those to measure the robustness, the resilience and the stability of the system. For example, research projects funded by EU Horizon 2020 develop resilience approaches in the domains of critical infrastructures (Resilens, 2016; SmartResilience, 2018) or urban transport systems (Resolute, 2016). Pavard et al. (2009) indicate that the notions of robustness and resilience have become central in many scientific fields ranging from computer science to biology via ecology or finance. In the literature, there is not a single well-accepted definition for the terms robustness and resilience (Cai et al., 2018; Shahrokni and Feldt, 2013), but rather a global vision of these two concepts.

On the one hand, the notion of robustness refers generally to the ability of a system to resist, maintain a state despite a set of disturbances. On the other hand, the notion of resilience emphasises the ability of a system to recover and adapt to a set of disturbances, with an absorption phase and a response phase. The notion of resilience is also characterised by the delay in which the system returns to an acceptable state. Robustness and resilience of a system is appreciated relatively to a set of disturbances, a system is robust faced to a set D_1 of disturbances identified a priori, the same system

can be qualified as resilient faced to another set D_2 of disturbances identified a priori. D_1 and D_2 are not necessarily equal, some disturbances can appear in the two sets but not all. Some definitions highlight the cost of a resilience strategy, Haimes (2006) and Haimes et al. (2008) indicate that resilience approaches not only aims to recover the desired states of a system within an acceptable delay, but also at an acceptable cost.

Wang et al. (2017b) propose an analyses of the definitions of resilience. The authors distinguish qualitative and quantitative definitions of resilience. Classifications of qualitative definitions frequently distinguish definitions according to the domain of application: for instance these classifications may include categories as ecological resilience, system resilience, engineering resilience and organisational resilience. These categorisations are very interesting but they do not provide a better understanding of the meaning or the subtleties underlying this concept. Roostaie et al. (2019) propose an original analysis considering both areas in which resilience has gained substantial traction (academic literature, government regulations and among private and non-governmental organisations) and a specific degree of normality in the definition, namely descriptive, hybrid and normal concepts. Concerning robustness, there is no previous reviews or systematic reviews concerning the definitions of robustness on its general sense (Shahrokni and Feldt, 2013). However, there are some studies that consider specific domains of application as the work of Shahrokni and Feldt (2013) concerning software robustness.

The concepts associated with these two terms are very important for managers of critical systems, so the ability to correctly define them is crucial. Several authors (Martin-Breen and Anderies, 2011; Hassler and Kohler, 2014; Hosseini et al., 2016; Kamalahmadi and Parast, 2016; Wang et al., 2017b; Reyes Levalle and Nof, 2017; Roostaie et al., 2019) have proposed overviews or analysis of definitions of robustness or resilience, but there is no work considering both concepts simultaneously. The need of guidelines for using these concepts and terms in a coherent way is particularly important for researchers and practitioners of all domains.

Given these observations, this paper aims to identify the main similarities and difference between the concepts of resilience and robustness. The paper also analyses and discusses the concepts in order to classify the definitions through a typology related to their uses. To achieve these objectives, we have conduced a structured literature review related of the papers using both terms simultaneously.

The purpose of this article is to give an overview of the definitions of the two concepts of robustness and resilience in the literature review and specify the definitions that should allow better use of these terms.

We conducted a structured literature review on robustness and resilience definitions using published literature using both terms from 1975 to 2018. We posed three research questions:

1 What were the common definitions of resilience and robustness across disciplines?

2 What were the common aspects and differences in the definitions of resilience and robustness?

3 What were the typologies of definitions?

To address these questions the article is structured in five sections. After an introduction (Section 1), Section 2 presents the research method used to conduct the literature review.

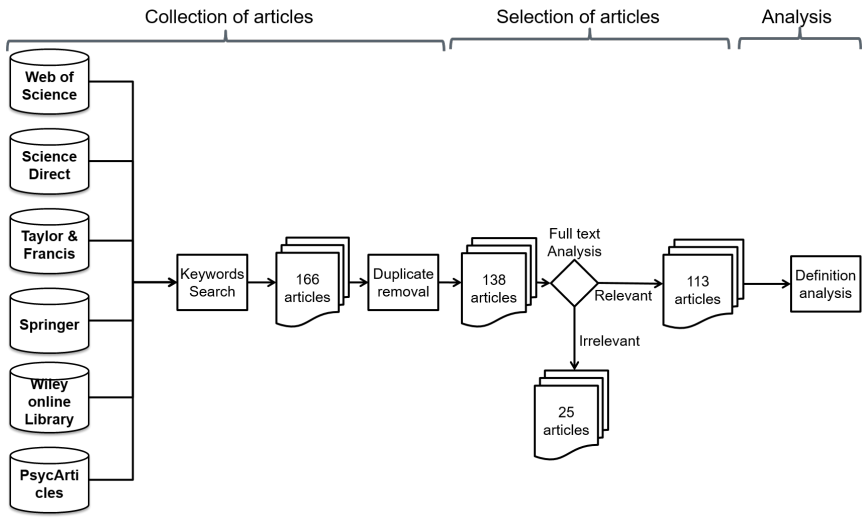
The overall analysis of articles and journals identified according to various criteria is presented in Section 3. Section 4 details the results of the bibliographic analysis of definitions and discusses the definitions by domain, trying to identify commonalities and divergences. A conclusion is proposed at the end of the article with a summary of major findings in research and their implications.

2 Research method

The first step of this research was to identify relevant articles to analyse and compare the definitions associated with the concepts of robustness and resilience. To achieve this goal, we adopted a literature review approach. The search method used to perform this analysis is presented as a process (see Figure 1) and has three main phases:

- collection of articles
- selection of articles
- analysis and classification of definition.

Figure 1 Process of the methodology



These three main phases are detailed in the next sections.

2.1 Collection of articles

To identify articles offering robustness and resilience definitions, a structured search was conducted. First, six main databases of scientific articles were identified: Web of Science, Science Direct, Taylor and Francis, Springer, Wiley Online Library and PsyArticles.

The article search in these databases was conducted using a combination of the terms ‘robustness’ AND ‘resilience’ in their title and keywords. The purpose of using

these search criteria was to identify articles that could potentially address both concepts in their development and propose respective definitions. However all the processed databases do not allow to use both title and keywords in the search method. So, due to specific functionality of scientific database research engine some searches had to be reduced only to the title as shown in Table 1 column 'scope of the research'. Varying the scope of the search may introduce a source of bias but we decided to accept it in order to maintain a sufficient number of articles in the analysis, considering it would be negligible. The column 'number' indicates the number of articles identified with the associated search in each database. Only the papers considered as article are kept in the analysis. Only papers written in English in peer-reviewed journals were considered.

Table 1 Type of research according to the database

Database name	*Scope of research*	*Number*
Web of Science	Title	54
Science direct	Title and keywords	51
Taylor and Francis	Title and keywords	25
Springer	Title	10
Wiley	Title and keywords	23
PsycArticles	Title	3

By adding the number of articles identified in each database, we obtain a total of 166 articles. However, some articles could be present in several databases. So the duplicate removal action avoids the redundancy of an article. After this operation, the first search, excluding duplicates, conduced to identify 138 articles.

The content of these articles is analysed in the next section (see Figure 1).

2.2 Selection of articles

The aim of the selection phase is to filter the articles, based on a reading of the full text, in order to retain those who explicitly propose definitions of at least one of the two terms. Thus, only relevant articles for our analysis are kept. An article is considered irrelevant when it does not give, in the text, definitions of the words robustness or resilience. An article is considered relevant if the author gives at least the definition of one of the two terms (robustness/resilience). During this phase of 'full text analysis', 25 articles of the 138 articles selected were considered irrelevant. So, 113 articles were retained because of their relevance with the aim of the study.

2.3 Analysis and classification

The purpose of the analysis phase is to identify the definitions and to compare them with regard to various criteria. More precisely, we choose to analyse each definitions regarding the field of research, the type of application, the publication year and the name of the journal. The various analyses will initially concern the distribution of relevant articles according to the years, followed by the distribution through macro-categories. A cross-vision of the year and the domains will be present to conclude this first part (Section 3). In a second part (Section 4) an analysis of the robustness and resilience

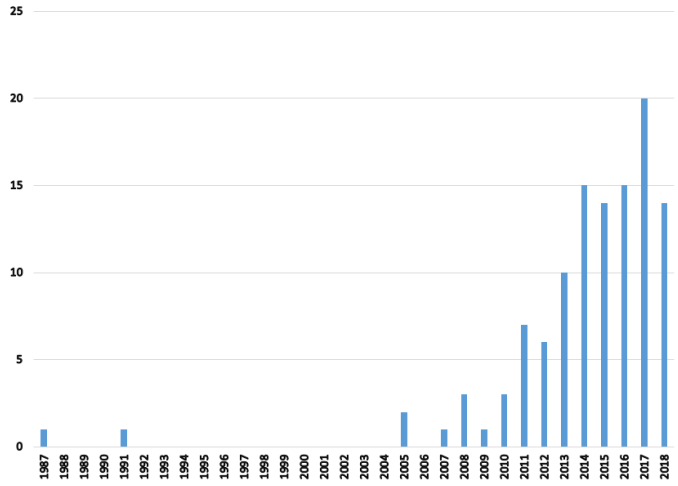
definitions will be made and then synthesised to finish with a cross-view of the different concepts in order to observe the distribution of the articles selected by our methodology.

In the end, we want to identify if there are any convergences, common points or differences in the definitions of these terms over time or according to domains. One of the aims of our work is to create a typology of concepts of resilience and robustness as used in the articles identified. The analysis of the definitions are detailed in Section 4.

3 Distribution of articles across time and scientific domains

The analysis presented in this section is based on 113 relevant articles. The chart illustrating the distribution of articles by year (Figure 2) shows that the use of both terms at the same time appeared in one article in 1987, followed by another article four years later in 1991. The major publishing of articles containing both terms started in 2011-2012. During the twenty years the joint use of these terms in the same article remained moderate. From 2011-2012, there is an increasing of articles using simultaneously these two terms.

Figure 2 Distribution of the number of articles across the time (see online version for colours)



Figures 3 and 4 correspond to the extraction of the number of articles present in the WOS between 1975 and 2018 respectively using in their title the words robustness and resilience. We note that the evolution of these two separate terms increases around the year 2000. To understand the difference between the evolution of the two terms separated and their comparison, we must look at the etymology of robustness and resilience.

According to Bradley (1978) robustness comes from the 1950s in the field of mathematics and many authors use it to evaluate the different tests performed. According to Bradley (1978), “the author’s overgeneralisation, underqualification or use of overly exuberant language in proclaiming robustness further tends to convey the impression that robustness is a highly general phenomenon”, the definition of robustness is used qualitatively, which allows many authors to adapt it as it sees fit.

According to Tisseron (2007) the resilience has two origins: one coming from the French Middle Ages having the notion of "retracting a contract by a kind of leap backwards" and the other one of an evolution in the English language in the 17th century "which the idea of post-shock reaction: the rebound" explains that the American history of this word will create a great diversity of definitions and the use of this term in psychiatry. In conclusion he ends by saying "the same word used by three interlocutors interested each one by a different field will necessarily have three different meanings." The importance for him on the word resilience is to agree on the definition of this term to be able to have the same vision and to understand himself when using it.

Figure 3 Evolution of the use of the term robustness in the WOS (see online version for colours)

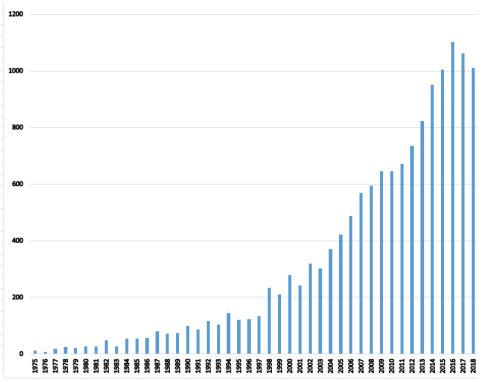
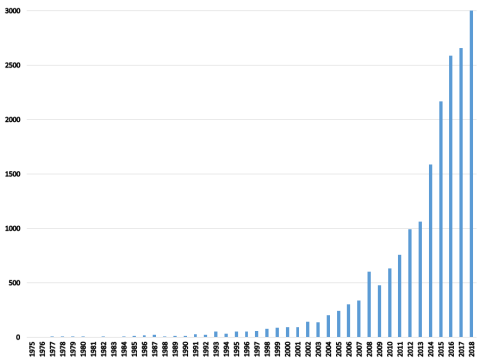


Figure 4 Evolution of the use of the term resilience in the WOS (see online version for colours)



This view of the terms on their etymology shows that their definition is used in relation to a global aspect of the concepts but also that the two concepts, robustness and resilience, come from different domains.

The articles identified were published in no less than 94 journals. Thus, there is no journal that can be put forward because of an important number of articles dealing with these two terms. All the journals identified have published between one and four articles: *Ecology and Society*, *Earth's Future*, *Reliability Engineering and System Safety*, ...

Table 2 Domains analysis

Domain (number of papers)	*Authors*
Engineering (42)	Alenazi and Sterbenz (2015), Schlichtmann (2016), Weide-Zaage et al. (2018), Fryer et al. (1987), Zhu and Basar (2015), Lucas et al. (2018), Okoh and Haugen (2015), Wybo (2008), Balzari and Balzari (2017), Huizar et al. (2018), Corman et al. (2018), Faber et al. (2017), Dias (2015), Adenso-Díaz et al. (2017), Spiegler et al. (2012), Ivanov et al. (2014), Mens et al. (2015), Faber et al. (2018), Wang et al. (2014), Pien et al. (2015), Jenelius and Cats (2015), Calvert and Snelder (2018), Wang et al. (2017b), Feng et al. (2017), Artsiomchyk and Zhivitskaya (2013), Sun et al. (2017), Klibi et al. (2010), Ivanov and Sokolov (2013), Huang et al. (2017), Wang et al. (2017a), Kim et al. (2017), Barabadi and Ayele (2018), Liu et al. (2018), Hernandez et al. (2014), Kanno et al. (2017), Ouyang and Dueñas-Osorio (2014), Salehi Sadghiani et al. (2015), Huang and Zhang (2016), Di Nardo et al. (2017), Ibanez et al. (2016), Ivanov et al. (2015) and Zhang et al. (2011)
Computer science (17)	Sha and Panchal (2013), Martin and Ludek (2013), Read (2005), Camara et al. (2017), Mercer et al. (2016), Greco et al. (2012), Klau and Weiskircher (2005), Kamissoko et al. (2013), Ponnambalam et al. (2014), de Souza and Zhou (2015), Houthooft et al. (2015), Yang et al. (2014), Yoo and Yeo (2016), De Florio (2012), Miller-Hooks et al. (2012), Alenazi et al. (2014) and Papadimitriou et al. (2016)
Agronomy (4)	Urruty et al. (2016), Bouttes et al. (2018), Friggens et al. (2016) and de Goede et al. (2013)
Biology (14)	Levin and Lubchenco (2008), Aschbacher et al. (2014), Butler and Silver (2009), Ukraintseva et al. (2016), Whitson et al. (2016), Prostova et al. (2015), Kaiser et al. (2007), Roche et al. (2017), Varadhan et al. (2018), Tagore and De (2011), Santarnecchi et al. (2015), Timóteo et al. (2016),Sydow et al. (2016) and Khanmohamadi et al. (2018)
Ecology and environmental (23)	Abimbola and Topp (2018), Mumby et al. (2014), Dragicevic (2016), Krupa et al. (2014), Anderies et al. (2013), Anderies and Hegmon (2011), Fleischman et al. (2010), Domptail et al. (2013), Witten (2014), Nair and Howlett (2016), Borgomeo et al. (2018), McPhail et al. (2017), Muneepeerakul and Anderies (2017), Minoarivelo and Hui (2016), Albert et al. (2013), Donohue et al. (2013), Valdovinos et al. (2010), Ayyub (2014), Guivarch and Monjon (2017), Yazdani et al. (2011), Mens et al. (2011), McDaniels et al. (2008) and ten Napel et al. (2011)
Zoology (1)	Rollo and Shinata (1991)
Social science and psychology (6)	Baggag et al. (2018), Scholz et al. (2012), Capano and Woo (2017), Beattie et al. (2011), Amantini et al. (2012) and Kuntz et al. (2017)
Management (3)	Brandon-Jones et al. (2014), Tempels and Hartmann (2014) and Edgeman (2015)
Business (3)	Tieman (2017), León and Berndsen (2014) and Kristianto et al. (2017)

Table 2 shows that these two terms are used in a multitude of domains. Based on the categorisation of these journals (Web of Science categories), we have identified nine major domains: engineering, computer science, agronomy, biology, ecology and environmental, zoology, social science and psychology, management, and business. We have merged original categories, based on the domain classification of the WOS repository, in macro-categories because the WOS allows the articles to be classified in several categories and that only the main one concerns us and different bases not having exactly the same categories so an article in doubloon was classified in different categories according to the base. This explains the grouping of 'social science and psychology' and 'ecology and environment'.

Table 2 references the authors according to these major domains of their article. For each category, the number of articles identified is given. The three significant domains are 'engineering', 'ecology and environmental' and 'computer science'. They represent respectively 37%, 20% and 15% of the articles analysed.

Table 3 Robustness domain in the WOS

Domain	*Number of papers*
Engineering	5,589
Computer science	6,365
Agronomy	74
Biology	992
Ecology and environmental	410
Zoology	42
Social science and psychology	259
Management	759
Business	438

Table 4 Resilience domain in the WOS

Domain	*Number of papers*
Engineering	2,109
Computer science	1,948
Agronomy	61
Biology	2,671
Ecology and environmental	4,546
Zoology	49
Social science and psychology	6,526
Management	670
Business	741

Tables 3 and 4 present the analysis of the WOS extractions of the articles having in their title the word robustness and respectively resilience. The grouping of the categories is represented only on the categories present in our analysis to be able to observe the different uses of the two words. Using these tables, domains shows a greater interest in robustness like 'engineering' or 'computer science'. While for resilience, the dominant areas are 'social science and psychology', 'ecology and environmental' and 'biology'. More and more domains need both terms to characterise their system. A cross-view

between the year and the field of relevant articles shows the dates from which the comparison between robustness and resilience begins to be made in each domain.

Table 5 Comparison years/domain

Domain/years	*1987*	*1991*	*2005*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Engineering	1				1		1	1	1	2	4	9	3	11	8
Computer science			2						3	3	3	2	3	1	
Agronomy										1			2		1
Biology				1	1	1		1			1	2	4	1	2
Ecology and environmental					1		2	4		4	4		3	3	2
Zoology		1													
Social science and psychology								1	2					2	1
Management											2	1			
Business											1			2	
Main periods	19 papers – moderate interest								94 papers – increasing interest						

The years/domains analysis (Table 5) shows that the simultaneous use of the terms resilience and robustness has developed a little earlier in three domains (computer science, engineering and biology). Then, this comparison spread in 2011–2012 across all other domains. The notions of resilience and robustness have existed for a long time and in many fields. This first analysis highlights that the use of these two terms is much more recent.

4 Analysis of definitions

The authors of the 113 articles analysed employed both terms resilience and robustness. The full text reading of these articles revealed some disparities related to the meaning of these words. Among these 113 articles a lot of authors give a very precise definition of the terms robustness and resilience. But some authors give a very unclear vision or even no definition of the terms used. It is important to note that even though the articles are grouped by categories, there is a great diversity of situations covered in the articles.

The first definition of resilience in the ecological domain was proposed by Holling (1973) who studied this property in relation with the evolution of ecological systems. Linkov et al. (2014) propose to define resilience as “the ability to anticipate, prepare for,and adpat to changing conditions and withstand, respond to, and recover rapidly from disruptions.”

Authors, as Holling (1996), distinguish two forms of resilience: engineering resilience “concentrates on stability near an equilibrium steady state, where resistance to disturbance and speed of return to the equilibrium are used to measure property”, while ecological resilience “emphasizes conditions far from any equilibrium steady-state, where instabilities can flip a system into another regime of behaviour, that is, to another stability domain.” In fact, engineering resilience focuses on maintaining efficiency of function while ecological resilience focuses on maintaining existence of the function.

Engineering and ecological resilience deal both with dynamic systems (Reggiani et al., 2015).

We have attempted to analyse the meanings of concepts of robustness and resilience as developed in the articles and then to categorise them in main categories. The full text analysis revealed three main types of robustness definition and three main types of resilience definition.

4.1 Three main types of robustness definitions

For the notion of robustness, differences between the three types concern either an acceptable zone or a different description of the system by using the main and secondary functions. The type 1 robustness, illustrated in Figure 5, is a definition of robustness oriented on the fact that the system remains invariant, unchanged in the face of disturbances. When a disturbance occurs, the indicator allowing to observe the behaviour of the system impacted does not change, it still has the same value.

The type 2 robustness corresponding to Figure 6 is close to the type 1 robustness, however, the authors accept that the system is slightly modified. A system is considered type 2 robustness if it remains in an acceptable performance defined for the system during disturbances. The authors are interested in maintaining an acceptable level of performance. The performance level must keep in this acceptable zone but it can oscillate/fluctuate between the boundaries.

The type 3 robustness (Figure 7) introduces a new viewpoint for defining the concept of robustness. The authors distinguish the main function of a system from its secondary functions. They consider the robustness of the system as the invariance of the main function as for the type 1 robustness but there is the possibility that the secondary functions are damaged by the disturbance. So, after the disturbance event, the main function stays effective while the indicators reflecting the behaviour of the secondary functions show that they are degraded and unstable.

These three types of definition of robustness are close to each other. But its add slight features allowing each user to find his vision of robustness according to the system he is studying.

Figure 5 Type 1 robustness (see online version for colours)

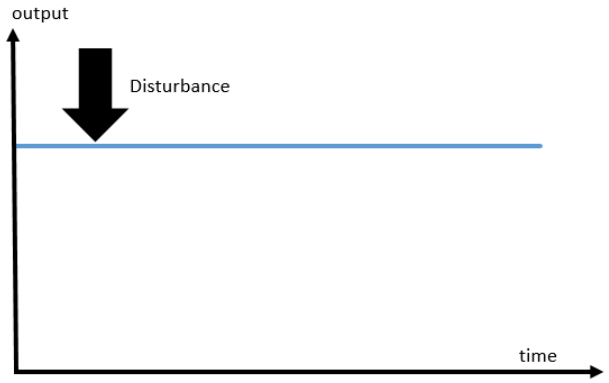


Figure 6 Type 2 robustness (see online version for colours)

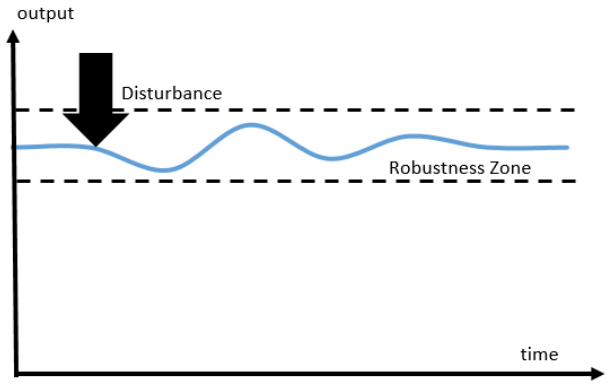
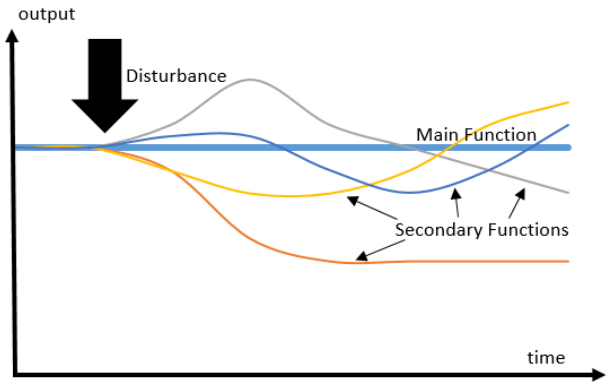


Figure 7 Type 3 robustness (see online version for colours)



4.2 Three main types of resilience definitions

Concerning the concept of resilience, we have also identified three main types of definition. Their differences will be on the zones of absorption and response but also on the return to a stable state.

The type α resilience (Figure 8), aims to define a system as resilient if it is able to absorb the disturbance with a deterioration of the performance without it being dramatic and then a capacity to return to the original level of performance of the system.

The type β resilience (Figure 9), is similar to the type α resilience, however authors do not absolutely seek a return to the original level of performance. They prefer to define an area associated to a specific level of acceptance. The disruption can conduce the system to work outside the boundaries of the acceptable zone. The resilience of the system is then defined as the capacity of the system for returning to this zone after experiencing a disturbance.

For type γ resilience (Figure 10), it is not the notion of absorption and response that the authors put forward but rather the notion of adaptation. A system is of type γ resilience when after a disturbance the system adapts and continues to operate stably. So there is a transition from the original state to a new state. The three types of resilience

have a common aim of adaptation after disruption, whether through absorption and return to the original state or an acceptable level, or the stabilisation in a new state.

Figure 8 Type α resilience (see online version for colours)

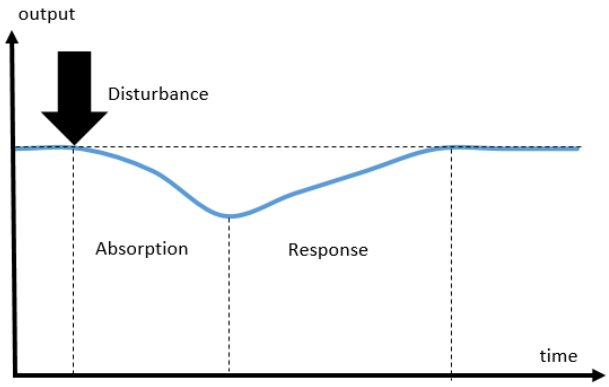


Figure 9 Type β resilience (see online version for colours)

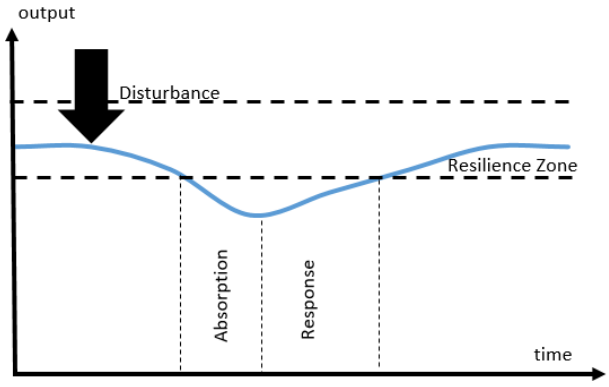
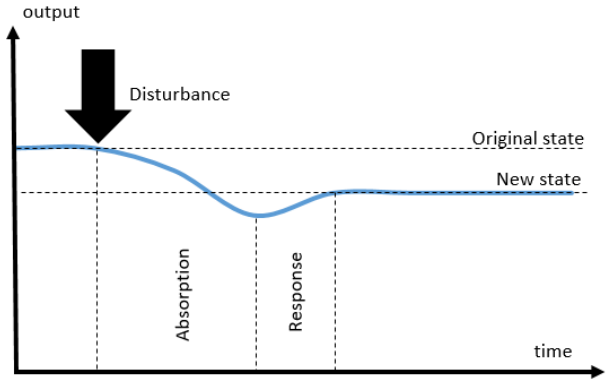


Figure 10 Type γ resilience (see online version for colours)



As Kamissoko et al. (2013) stress the importance of defining the characteristics on which the system is evaluated. These characteristics can correspond to the time to return to the acceptable state, the maximum degradation of the system, the deviation from the original state accepted, the times of the absorption and response phases...

4.3 Classification of the articles through the three main types of definition

The full text analysis has allowed to distinguish and to characterise three types of robustness and three types of resilience. Then it is interesting to know how the articles are distributed through these categories. Tables 6 and 7 correspond to the distribution of the articles according to the three definitions of robustness given previously and of resilience respectively. 80% (91/113) and 71% (80/113) of the articles are classified in the three types of definitions. Type 3 robustness is the least represented of the types. Probably because other authors do not precisely define their system distinguishing main and secondary functions. Moreover, articles do not all provide a specific definition of robustness. For the resilience the type α is the majority, in the same way as for the robustness, some articles only deal with a return without specify if it is about the initial state, of a zone of resilience or a new state. We propose to analyse papers according to what type of definition of the concept of robustness that they used related to the type of definition of the concept of resilience used. For this analysis, we introduce three other attributes:

- other definition, for papers that use another definition than those defined previously. Some authors give a definition of the terms robustness and resilience but far from the conceptualisation of other authors
- inversion, for cases where the authors switch the concept of robustness and resilience
- none, for papers who do not define clearly either the concept of robustness or the concept of resilience.

Table 8 shows the results of the analysis. However not all authors position themselves in the three types of robustness and resilience.

Table 8 shows that 113 articles are using the words robustness and resilience in their title or keywords.

For the nine boxes corresponding to the intersection between the robustness definitions type 1, type 2 and type 3 with the definitions of resiliency type α, type β and type γ, 63 articles (21 + 12 + 3 + 8 + 1 + 0 + 12 + 6 + 0) (56%) propose a definition of robustness and resilience in the three categories described above. The dominant type of robustness is type 1. For robustness, the type 3 is the least used. However, the definition appears close to type 1 because it considers the difference between the main and the other system functions. Not all authors made this distinction when studying their system. The dominant type for resilience is the type α. However type β and type γ are often used, the studied system is classified in a type of resilience according to what the author seeks to put forward in the system but especially to know how it adapts to the disturbance.

Table 6 Type of robustness

	Type 1	*Type 2*	*Type 3*	*Total*
Number	55	29	7	91

Table 7 Type of resilience

	Type α	*Type* β	*Type* γ	*Total*
Number	42	16	22	80

Table 8 Robustness and resilience

		Robustness			*Other*	*Confusion*	*None*	*Total*
		Type 1	*Type 2*	*Type 3*				
Resilience	Type α	21	12	3		1	5	42
	Type β	8	1			2	5	16
	Type γ	12	6				4	22
Other					2			2
Confusion		1		1		1	2	5
None		13	10	3				26
Total		55	29	7	2	4	16	113

For the column and the row 'other', two papers (Yang et al., 2014; Wang et al., 2014) are identified. For these authors the notion of robustness does not correspond to a maintenance of performance during a disturbance but the robustness of a system is measured during uncertain disturbance, "robustness relates to uncertainties in the plant" (Yang et al., 2014). For the notion of resilience, it is not a phenomenon of absorption and response but the authors finally speak of a model of known disturbances or we can act on it with the help of parameter, "resilience relates to perturbations in the implementation of a controller, especially of a digital controller in order to have a certain degree of freedom in the choice of controller parameters" (Yang et al., 2014).

For the column and the row 'confusion'. Among the analysed articles, only 1 author reverses the definitions of robustness and resilience (the confusion/confusion box). Anderies and Hegmon (2011) define robustness as "the sensitivity of a particular desirable system output in response to external variation" corresponding to the definition of type α resilience and he defines the resilience as "the size of shock a system can sustain and still maintain its structure and function" corresponding to the definition of the type 1 robustness. The other articles in the row and the column 'confusion' finally correspond to authors giving the same definition for the terms of robustness and resilience but it may have made slight differences. Weide-Zaage et al. (2018) define the resilience as "the ability to reduce the amount and effect of hazards, unexpected failure mechanisms and their consequences." In their article the description appear similar to the type 2 robustness.

Finally 42 articles (26 + 16) (37%) do not offer a definition of one of both terms (corresponding to the row and column 'none'). In these articles, it is unclear whether the authors consider the two terms as a single one or whether they favour one in their

research. However even if they do not define the two terms the majority of them position themselves in the different types of definitions previously written in the article for the other term.

To choose the type of robustness, it is important to choose the studied system and the observed output. Then one should know if the system must be robust in its entirety or only on certain functions. And finally you have to know if you consider a total invariance or if the system can vary in an acceptable area. Type 1 robustness corresponds more easily to systems viewed globally with total invariance. Type 2 robustness is close to a system with the right to vary within acceptable limits. Type 3 shows a system where the aim is to preserve the main function.

To choose the type of resilience, it is important to choose the studied system and the observed output as for robustness. The remaining choice relates to the return zone, either on the original state or an acceptance area. The notion of new state is a fact allowing to choose the type of resilience. Type α resilience corresponds to the study of a system until it returns to its original state. Type β resilience corresponds to the study of a system that returns to an acceptance zone. And type γ resilience corresponds to the study of the system until a new state.

4.4 Applications of this typology for companies and decision-makers

The impact of the COVID-19 pandemic illustrates the interest of the typology of the concepts resilience and robustness. We observe that the proposed typology in this paper enables to classify the recent research works related to the resilience and robustness of organisations that were faced by the COVID-19 pandemic. For instance, in the supply chain domain (Ivanov and Dolgui, 2020) presents a type α resilience where the objective is to assess the return to the initial state following a disturbance, by taking into account the medium and long term impacts of the crisis. Conversely, Montreuil (2020) focused on type β resilience as he considers the supply chain should return to a satisfying state. In the medical field, Austin and Gregory (2020) follow a type γ resilience by defining resilience as the ability to adapt and to maintain psychological equilibrium. For example, hospital staff had to maintain their ability to work despite the pandemic context and the state of high stress. Although few researches related to robustness in this specific context are published, this notion is also adapted to the current pandemic situation, as the impact of the disruption is too great for an organisation to remain unchanged. With a more macroscopic approach, it can be hypothesised that in case of an extreme and rare situation such as a pandemic, robustness and resilience can be understood as a means of handling the spread of the phenomenon as ripple effect (Sokolov et al., 2016; Dolgui et al., 2018), bullwhip effect (Dominguez et al., 2014; Thomas and Mahanty, 2019)...

To cope with disruptions, a company may seek to improve its resilience and robustness. This typology could help it in this process by enabling it to structure its thinking. It could first help it to assess the type of resilience and robustness of its organisation and resources, to define those they wish to achieve and to develop relevant monitoring indicators. Methods such as feedback, setting up a scenario, tests, simulations, etc. can be used to verify and to evaluate that the system requirements are met despite the disruptions.

5 Conclusions

Over the past decades, the concepts of robustness and resilience have been well recognised among researchers and practitioners. The terms are increasingly used in research journals, government documents, and the media but definitions are not well shared and work remains on making standard definition. The objective of this paper is to provide a comprehensive analysis of definitions used in scientific articles and to identify commonality between these definitions. A multidisciplinary structured analysis was performed and 138 international journal articles were reviewed. These articles were published from 1975 to 2018 and show that authors are increasingly comparing the terms robustness and resilience in many areas. This article highlights a lack of definition for robustness and resilience in many studies. The contribution of this article is to give a classification of the different definitions of robustness and resilience proposed in the literature. Three variants of definitions have been identified for each of the two terms and graphical illustrations are given allowing to visualise and exemplify small differences. The notion of robustness refers rather to invariance in the face of a set of disturbances. While resilience is concerned with an adaptation phenomenon (absorption/response) facing a set of disturbances. The totality of the disturbances taken into account in both definitions can be different as much about the nature of the disturbances as their intensity. These two concepts, robustness and resilience are complementary. The need to define a system as accurately as possible probably explains why authors address both terms simultaneously. Decision makers and researchers can benefit from our survey since it introduces a structured analysis and recommendations as to which definitions can be used. Some of the confusions identified in the literature can be blamed on the complexity of understanding the concepts of robustness and resilience. The difficulty to grasp these concepts conduces sometimes to use not adapted words. So, the classification we proposed permit to introduce the subtleties in the definitions of these concepts and to guide researchers and practitioners to use the good term to qualify what they want to say.

Analysis of robustness and resilience definitions is, in conclusion, a field of study that can have a positive impact on standardisation and more comprehensive development of approaches to enhance the system's ability.

One prospect for future researches could be to establish a correlation between the types of robustness and resilience used in relation to the activity sector, managerial level, maturity of the company or other factors.

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