Chapter 11
Competence as Enabler of Urban Critical Infrastructure Resilience Assessment

Florian Brauner, Marie Claßen and Frank Fiedrich

Abstract Providers of urban critical infrastructures are often relying on indicator-based approaches for resilience management. While science is developing more and more intelligent resilience indicators, the application and interpretation of such indicators might lead to new challenges and questions. Since models always reduce the complexity of real world systems, users of the developed indicators need to understand the underlying assumptions. Otherwise, simplifications may lead to misinterpretations and severe consequences for the infrastructure providers and the society. In this chapter the authors discuss the difficulties related to the development and usage of resilience indictors and present relevant quality criteria for their evaluation and selection. Additionally, proper resilience assessment requires expert skills and an advanced knowledge and competence profile. Bloom's learning taxonomy provides the theoretical underpinning which may be used to develop such profiles.

Keywords Critical infrastructure protection · Resilience indicators
Ethical consequences · Competence-oriented resilience assessment
Quality management · Resilience engineering · Implementation challenges

11.1 Introduction

In this chapter, the authors display an integrated understanding of resilience and required competences to handle the interpretation of new resilience approaches. While science is providing more and more intelligent resilience indicators, the

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application and interpretation of such indicators might lead to new challenges and questions: e.g. who can handle such indicators and understand the different scientific models? What happens if resilience indicators are used in a wrong way, what consequences have to be expected?

Today resilience indicators are used to reduce the complex reality for quantifiable figures. Different scientific methods and models are used for this reduction and the resulting figures are often the basis for actions, such as the implementation of a different security design/ set-up or changes in the processes.

The quality of this procedure relies on different factors (a) a holistic understanding of the "world"/system the end-user wants to assess, (b) resilience indicators which address the problem the end-users want to be solved and (c) the competences of the end-users to understand the methodology behind the created indicator to reduce contextual deficiency.

While a lot of literature addresses the first two factors, the authors of this chapter focus on the last factor which is relevant for a valid outcome of the operationalisation of the resilience indicators.

11.2 Urban Critical Infrastructure and Their Social Importance

Today's western society is strongly dependent on products and services of Critical Infrastructures (CI). The US Department of Homeland Security identified 16 CI sectors "[…] whose assets, systems, and networks, whether physical or virtual, are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect e.g. on security, national economic security, national public health or safety, or any combination thereof" (DHS 2016).

While CI themselves are changing continuously and face challenges such as changing paradigms, emerging new technologies, demographic change, etc., there are additional risks and threats facing these infrastructures such as natural disasters, (un-)intentional human misconduct and/or (cyber-)terrorism, etc. The consequences of long-time disturbances are manifold on the affected society. Therefore, many efforts are invested to decrease vulnerability and increase the resilience of CI [e.g. cp. NIPP—US National Infrastructure Protection Plan (DHS 2017)].

In order to influence the resilience positively, a broad understanding of CI and the internal processes is necessary. CI knowledge is not only a precondition for developing comprehensive methods of measurement and mathematical techniques to assess resilience, but also for an understanding of society as part of CI resilience. But what does "knowledge" or "comprehension" mean in context of resilience and critical infrastructure? Do we know enough about this complex system to be able to assess resilience in a qualitative manner?

11.3 The Challenge of Resilience Understanding

Before the authors start the discussion about resilience indicators and quality criteria, two different examples of resilience shall open the view of resilience and the different contexts:

In Germany—as well as in Europe—there will be different resilience challenges due to different threats and risks, e.g. the development of smart grids of electricity, gas and water supply, and different new technologies were implemented into the urban infrastructure such as smart metre and household devices to monitor and regulate the different demands according to the end-user needs. The “intelligent” information flow enables providers to react quickly to any changes in the smart grid systems. While the new technology offers a variety of possibilities to increase the resilience of supply chain processes, new threats such as cyber attacks, sabotage and data abuse can arise. To achieve a high level of resilience considering possible side effects, technology application may have to change the view. So, what factors influence the resilience of urban infrastructure positively and negatively? How do you assess the development in context of resilience thinking?

The second example focuses on the societal developments such as the demographic changes in the society. According to statistics and calculations from the Federal Statistical Office, in 2060 more than 20% of the population in Germany will be 65 years or older (approximately 23.6%) (DeSTATIS 2015). Along with this development, an increase of elderly population needs can be expected. What does this mean for societal “*resilience*”?

These two introducing examples reveal the challenge for understanding resilience depending on the point of view, the role and the context. Defining “resilience” from the former Latin word “*resilire*”, which means “*bouncing back*”, resilience describes the ability of a system to react to stress and to then revert back into the former condition. Today, many different definitions are publicized depending on the research discipline and/or the subject of resilience (e.g. human being, nature, environment, critical infrastructure…). The different views enrich the discussion about this topic, but also make research results difficult to compare. In our paper, “resilience” is defined as “the ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies. Whether it is resilience towards acts of terrorism, cyber attacks, pandemics and catastrophic natural disasters, our national preparedness is the shared responsibility of all levels of government, the private and non-profit sectors and individual citizens” (DHS 2015). Like most risks, resilience can be described through different influencing factors. These factors are mostly measurable using empirical research methods and displayed as indicators which describe the resilience of a system. Based on these indicators, decision-makers choose different measures in order to influence the resilience of the system positively and strengthen the processes.

These assessment processes are however difficult due to possible misunderstanding and misjudgement. Knowledge and the competence to use these indicators are often neglected key factors of resilience assessment. In the next section, the authors describe the concept of resilience indicators and how corresponding data can be collected.

11.4 Resilience Indicators—A Method of Measurement

To be able to investigate the phenomenon of resilience in the context of critical infrastructure, there is the necessity for an empirical approach to it. An empirical approach provides the opportunity to collect data about resilience in real-world environments, which is crucial for a better understanding and further progress in this area. This empirical access for resilience researchers can be enabled by indicators, which constitute a method to operationalize and measure resilience.

An indicator can be defined as a measurable/operational variable that can be used to describe the condition of a broader phenomenon or aspect of reality (Øien 2001, p. 130). As it is not possible to measure aspects of reality directly, we need to operationalize a theoretical construct or theoretical variable through the use of indicators (Jovanović et al. 2016). This operationalization enables us in turn to check the developed theoretical constructs through empirical evidence (Fig. 11.1). Transferring a theoretical construct into an indicator always means simplifying the complexity of reality, so that sometimes one theoretical variable needs to be measured by multiple indexes indicators (Cardona 2005).

As resilience is a broad phenomenon, which includes various dimensions, it remains a conceptual and technical challenge to be operationalised, especially when the measurement uses a system based on composite indicators, thereby several indicators linked to each other. Because of the various existing dimensions of the phenomenon resilience, it can be operationalised by indicators in many different ways. The "integrated resilience cycle" (Fig. 11.2), for example, visualizes the four dimensions of "mitigation", "preparedness", "response" and "recovery" of resilience, which are, as shown in a circle, time-bound phases of a resilience process

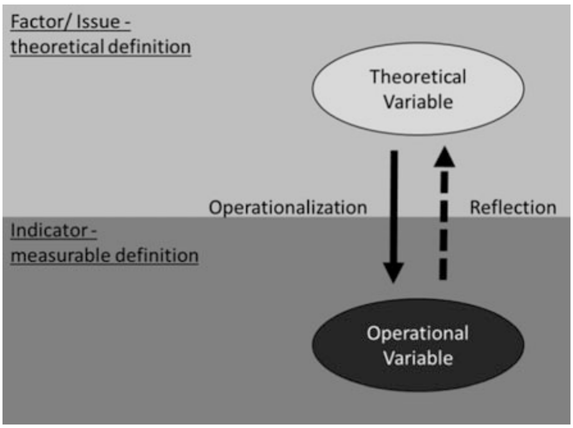

Fig. 11.1 Measurement model. (*Source* authors according to Øien 2001, p. 131)

(Edwards 2009) and each indicator usually only represents one aspect of resilience. Before referring to the concept of resilience, this model of a cycle with its diverse dimensions has been originally labelled as “disaster cycle” or “disaster management cycle” in disaster and risk management research (Alexander 2002).

Resilience indicators vary in their ability for representing the desired aspects of resilience. Therefore, it is of great importance to examine the suitability of a developed resilience indicator. For this purpose, various quality criteria or indicator requirements can be used as a tool to check the applicability of the indicator under consideration during, as well as after, the research process. These quality criteria ensure that the developed resilience indicator will be in accordance with a certain required quality level in order to label the indicator as an appropriate one.

11.5 Evaluating the Quality of Resilience Indicators

To develop an indicator to measure resilience without any quality control would withdraw the scientific character of the research process. The objective of scientific research is not only to gain a research outcome, but also to achieve an outcome which matches a standard of quality requirements. Not evaluating an indicator by quality criteria, as well as “inappropriate utilization of research findings outside

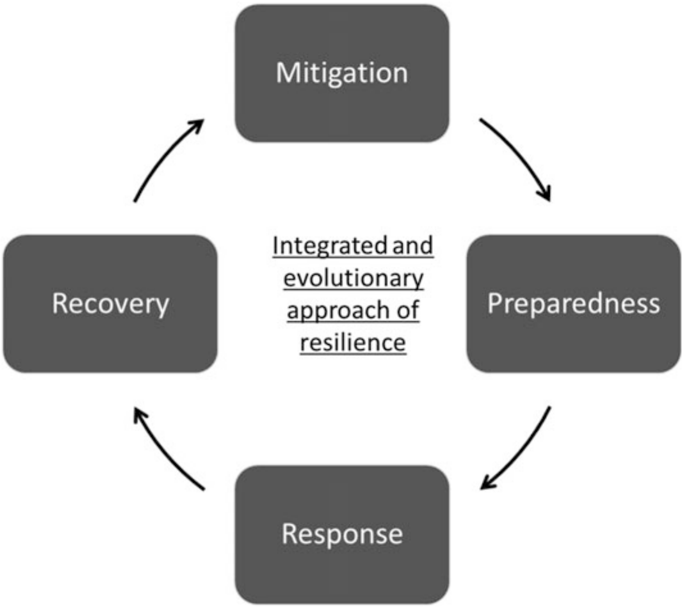

Fig. 11.2 Resilience cycle. (*Source* authors according to Coaffee et al. 2013, p. 9; Edwards 2009, p. 20)

clearly stated boundary conditions, can have serious and far-reaching methodological and ethical consequences" (Kimmel 1998, p. 40).

The best known and most fundamental criteria primarily connected with quantitative research are objectivity, reliability and validity. These three quality criteria have hierarchical links between them (Diekmann 2012). Objectivity is a necessity but not a sufficient precondition for reliability (Frauendorf 2006). Reliability in turn is a necessity but not a sufficient precondition for validity (Häder 2015). For a better understanding of their interdependencies, it is first necessary to comprehend each of them separately.

The criteria for *objectivity* are discussed controversially in literature. Some researchers argue that a state of objectivity can never be achieved—as science always involves a degree of interpretation—and they prefer the term of intersubjective agreement (Smaling 1992; Swanborn 1996). "Reaching for objectivity" means in its simplest form, as the authors want to use it here, to free research results from impacts by researchers. This then leads to researcher-independent outcomes. A distinction can be drawn between objectivity in *measurement* and objectivity in *evaluating*. Objectivity in measurement "can only be guaranteed if the person conducting the study has as little influence as possible on the respondents" (Frauendorf 2006, p. 181). In this sense, full objectivity is reached when two different researchers gain consistent results with the same measuring instrument (Diekmann 2012). Objectivity in the evaluation of the data obtained has normally no concern regarding resilience indicators because, in quantitative research designs, violations of this principle can only occur in relation to encoding errors (ibid). However, the interpretation and presentation of the results should be controlled as they "should merely refer to the facts of the findings" (Frauendorf 2006, p. 181) and not be manipulated by a researcher's subjective opinion.

Reliability can be defined as "a research procedure [that] should respond to the same phenomena in the same way regardless of the circumstances of its implementation" (Wolf 2008, p. 75). In other words, outcomes from an indicator should be accessible/ replicable by other researchers using standard methods (UN 2008). So objectivity in the sense of researcher independency has to occur here as well as the independency of a certain research occasion as "reliability relates to a stable and consistent measurement instrument" (Frauendorf 2006, p. 182). To determine the extent of reproducibility for the achieved research results, correlation coefficients can be calculated. So for the criteria of reliability, the reproducibility of the research outcomes has to be implemented through stability and measurability. Here, stability relates to "the research methods to be stable over time and as valid in the widest circumstances possible" (UN 2008, p. 7). In our case, measurability means that the description and interpretation of indicators have to be clear and reliable to avoid ambiguity and misinterpretation (ibid.). This leads to the possibility of a renewed measurement of the same indicator in a different setting.

To just have a certain level of objectivity and reliability (so that different researchers on two different occasions can gain consistent research results with the same research method) does not guarantee that a resilience indicator measures what it is supposed to measure. "*Validity* means, in a very general sense, that our propositions describe and explain the empirical world in a correct way; in a stricter sense: that they are free from random as well as systematic errors" (Swanborn 1996, p. 22). There can be distinctions drawn between diverse forms of validity (Wolf 2008). *Content validity* "is the extent to which all features that define the concept are measured" (ibid). This means the degree by which the chosen operationalization of the indicator represents the characteristics that were intended to be captured. Another form of validity is termed as *construct validity*. Construct validity "refers to the extent to which a measure is correlated with other measures of the same construct" (Wolf 2008, p. 80) and is used to verify or reject certain theoretical propositions, which are assumed to be linked to each other. This is of great importance to reveal new variables for further theory development. Furthermore, it can be distinguished between internal and external validity. *Internal validity* occurs when there is a variable due to the independent variable and alternative explanations can be excluded (Diaz-Bone and Weischer 2015). *External validity*, also termed as *generalizability*, "refers to the assumption that the research can be transferred to other business contexts and situations" (Frauendorf 2006, p. 80). The external validity of research findings increases by the number of replications conducted (Diaz-Bone and Weischer 2015).

The United Nations Secretariat of the International Strategy for Disaster Reduction stated on top of the already mentioned quality criteria *objectivity*, *reliability*, *validity* and some of their preconditions further requirements specifically for the quality of indicators (UN 2008).

One of them is *comparability* and defined by the UN (2008, p. 7) as follows, "the indicator measurement should enable comparison over the different lifecycle stages of the policy or project as well as between different policies or projects". This quality criterion addresses the benefit of comparing one's own research between different points and to interconnect with other findings of similar research, which then leads to a broader and better understanding of the subject matter.

Furthermore, the list of indicator requirements published by the UN (ibid.) contains the aspect of *relevance*: "Indicators should be directly relevant to the issue being monitored or assessed and should be based on clearly understood linkages between the indicator and the phenomena under consideration". By using this definition of relevance, the quality criteria of *currency* and *social benefits*, also considered by the UN, and the quality criterion of *applicability* referred to in other sources can be summed up together as parts of relevance.

Currency can be thematized in two dimensions: firstly, that the information of the indicator is as up to date as possible (UN 2008), and secondly, that the need of this indicator still exists. Social benefits relate to relevance insofar as there should be a societal profit due to the indicator or at least it should be stated for whom profit can be generated. Applicability as "the characteristic […] to be directly useful in a given context" (Eppler 2006, p. 79) is of great importance, as there can be only a sense or use of a developed indicator when it can be applied in practice.

Four additional indicator requirements discussed by the UN are *sensitivity*, *attainability*, *cost and time-boundness*, which the authors cluster together in the category called *maintainability*. Maintainability can be defined as "the characteristic […]

to be manageable over time at reasonable cost" (Eppler 2006, p. 79). Consequently, to gain maintainability it includes the aspect of sensitivity—"indicators should be able to reflect small changes in the things that the actions intend to change" (UN 2008, p. 7) as well as the aspect of attainability, which also includes sensitivity as "the measurement of the indicator which should be achievable by the policy or project and thus should be sensitive to the improvements the project/policy wishes to achieve" (ibid., p. 7). The aspect of costs arising from the operationalised indicator remaining reasonable and affordable (ibid.) and the aspect of time-boundness as "the time of an indicator's measurement, or the interval to which it applies, should be appropriate and clearly stated" (ibid.) are also crucial to gain maintainability of indicators.

Additionally, the UN (ibid., p. 7) proposes the indicator requirement of *comprehensibility*, which they define as "the definition and expression of the indicator should be intuitively and easily comprehensible to others". As it refers to potential users of a developed indicator, the authors prefer the general term of *convenience* which designates the ease-of-use for others not involved in the research. For the general term of convenience, the authors associate besides *comprehensibility* also *consistency* and *conciseness*. Consistency and conciseness enable data to be free of contradiction and convention breaks as well as to be expressed clearly and succinctly.

Lastly, the authors finalise the list of quality criteria with the criterion of *credibility* of the information which the indicator is based on. In this context, the UN (2008, p. 7) list refers to the aspect of *completeness* as "the data should be complete and free of missing values". Furthermore, the authors classify the already mentioned criterion of *consistency*, as well as *correctness* and *traceability,* as sub-criteria of credibility. Correctness means the data is free from error or fault and traceability ensures the possibility to trace back the whole research process and to check on its trustworthiness. The credibility of the information used, as well as the data generated, impacts automatically on all the other discussed quality criteria, as this criterion is the foundation for a successful application.

To fully apply all these quality criteria with resilience indicator is idealistic and cannot therefore be converted in practice. Some of them are even positioned as tradeoffs. For instance, conflicts can occur between the aim of completeness and the aim of clarity or conciseness of information (Eppler 2006). However, it is desirable to fulfil the quality criteria to the largest possible reasonable extent. Therefore, it has to be considered carefully, which criteria should and can be included and to which degree the criteria can be implemented by researchers. "In practice, indicators do not need to contain every characteristic. Depending on the indicator's nature and use, only a subset may be relevant" (UN 2008, p. 7). As some quality criteria are preconditions for others, like for example correctness for credibility or currency for relevance, characteristics overlap others to varying extents. Therefore, difficulties arise when separating them from each other to obtain a structured overview. Figure 11.3 shows the approach to arrange the discussed quality criteria in a reasonable and understandable way.

Evaluating and ensuring a certain quality level for a resilience indicator requires not only the existence of essential quality criteria, but also the knowledge and competence by a researcher and/or researchers to apply these correctly.

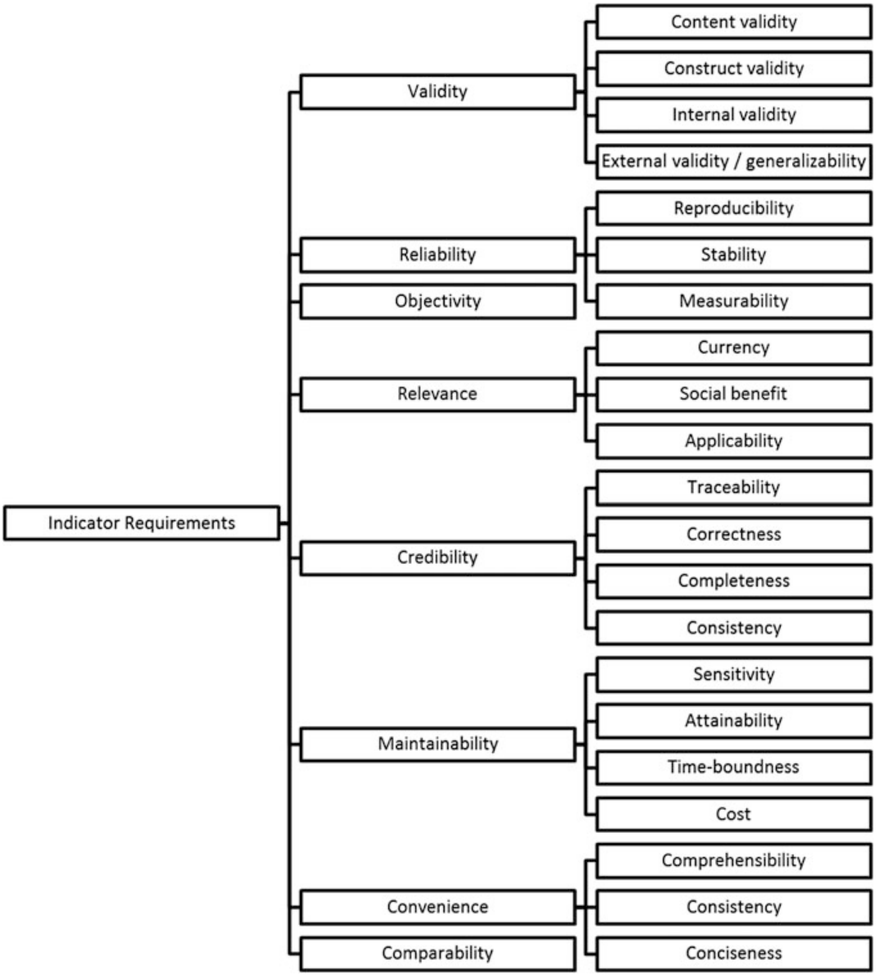

Fig. 11.3 Quality criteria of resilience indicators. (*Source* authors)

11.6 Knowledge and Competence to Ensure the Application of Resilience Assessment

In this section, the authors describe the meta-level of resilience understanding. Knowledge as an enabler requires a comprehension about content and context. Therefore, the different steps of learning according to the taxonomy of Bloom (1956) are used to analyse a resilience assessment competence profile. In the last section, the authors provide a set-up for the assessment of the quality of a resilience indicator. These criteria have to be taken into account for the application of resilience indicators, especially in the decision-making process for measures. But besides the existence of quality criteria, the process of compliance is still defective based on human misjudgement. So how can this risk be reduced to an acceptable level?

Firstly, the business processes and there influencing resilience factors of, e.g., critical infrastructures have to be understood (cp. Edwards 2009). Therefore, the process quality depends on all involved factors including the understanding of the structural requirements, knowledge about the methodology of resilience indicators as well as the competence of conducting/applying an indicator correctly.

In the following section, the authors focus on the competencies and skills of indicator-based resilience application. Educational sciences define skills as an ability based on knowledge, practice and/or aptitude to do something. This definition does not include the condition of being capable. A set of correct skills, knowledge and qualification leads to competences and to the capacity of actions. "Competence indicates sufficiency of knowledge and skills that enable someone to act in a wide variety of situations" (Business Dictionary 2017).

This implies that competence is more than just knowledge, abilities or skills; it enables actions in open and complex situations, even with an uncertain set of information. Therefore, it includes resolute actions within the framework of skills, knowledge and qualifications (Erpenbeck and Rosenstiel 2007).

In the 50s, Benjamin Bloom invented a model of competencies called Bloom's taxonomy in the context of education systems. In six different hierarchical steps, knowledge can be categorized according to the skills and application level. The model clearly explains the different levels of abstraction. It starts with the lowest level of competence, "the knowledge". Students on this level can easily repeat knowledge that has been taught by a teacher. On the second level, called "the comprehension", students have a higher understanding for being able to recall facts or information. The comprehension level allows an understanding of facts with a specific background, so knowledge can be described and discussed in one´s own words.

The next level, "the application", leads to first actions of knowledge. In addition to the second level, students are able to use the knowledge and information to solve a specific problem. For the first time, knowledge is used or applied to create new information. The autonomy of the individual students increases with this level, towards the fourth level called the "analysis". Students now have the ability to see patterns and to analyse problems. The investigation around the problem increases self-reliance that can be highly motivating in learning processes. In the next level of "synthesis", knowledge can be used to create new theories, predictions and conclusions. Therefore, information from various sources is processed into a new problem. This requires also the ability of imagination and creativity that empowers this competence.

In the last and highest level, "the evaluation", the ability for assessing information is elaborated. This enables information to be concluded according to its value or bias and to judge processes.

Bloom's taxonomy levels are a model for competence learning but, what started out as a model for teachers in a classroom setting, can be transferred to our case of

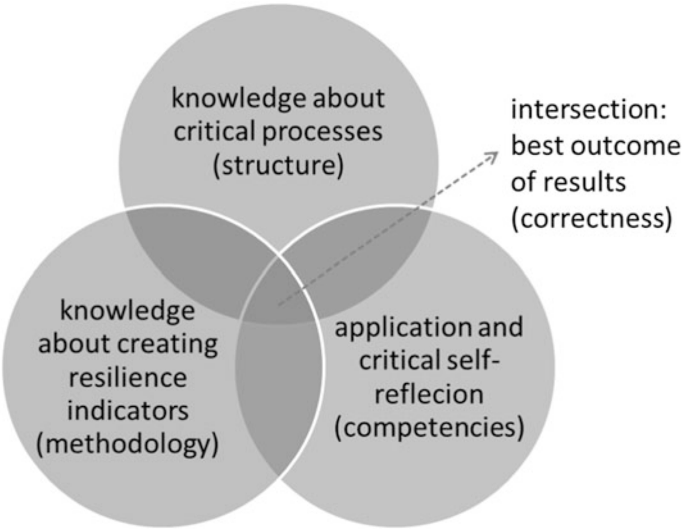

Fig. 11.4 Integrated knowledge understanding of resilience assessment. (*Source* authors)

indicator-based resilience assessment. *This leads to the research question, what is the right set off competences for resilience assessment of urban infrastructures?*

As shown in Fig. 11.4, the assessment of resilience indicators requires knowledge about the structure/environment as well as methodology, the knowledge needs to be processed (applied) and evaluated in the context of the research subject. As a result, the person who conducts resilience investigations needs competences at the highest level of Bloom’s taxonomy hierarchy. The evaluation of results is absolutely essential, because the results are then used to prepare critical decisions e.g. for the implementation of different security designs, the consequences from mistakes may be manifold. While Bloom’s taxonomy model helps to develop training and educational programs for qualifying as an expert, there is still an important factor missing in this discussion.

Besides the categorization of competences (taxonomy), the complexity of information and knowledge has to be considered as well in the discussion about resilience assessment. Although, the model displays a kind of increasing complexity and abstraction for information along the different levels of competencies, the processed information itself can have different grades of complexity.

Depending on the methodology for creating resilience indicators, the processed knowledge has different complexity itself. Therefore, the complexity has to be reduced according to the relevant systems boundaries (Allen 2001).

An advanced “knowledge database” is recommended to structure the used data as well as for guidelines to check the use of indicators according to the quality criteria as described above.

11.7 Conclusion—Advanced Resilience Assessment

Indicator-based resilience assessment is crucial due to the complexity and manifold consequences of misjudgement. Nevertheless, it creates great opportunities for a new understanding and control of resilience thinking. Therefore, a critical consciousness is needed in the execution and assessment of such indicators in three ways:

1. A holistic knowledge about the system and its critical processes is necessary!
2. The choice of methodology (resilience indicator making) has to strictly match the research question!
3. Users need the right set of competences to conduct the process of resilience assessment and reflect decisions and actions critically (self-monitoring)!

In this chapter, the authors introduced a set of quality criteria to assess resilience indicators and to ensure the process of indicator building. Furthermore, the experts themselves have been in the focus of the authors. The inspection of competence profiles revealed that resilience assessment requires expert skills in a high taxonomy level “evaluation” (cf. Bloom 1956).

To prevent an overload of information, the system boundaries have to be used carefully and documented in a structural manner such as guidelines and data management systems. In the future, evaluation of decision-making shall be included in the quality process of resilience assessment as well as training concepts for achieving the required competence profile for the analysts.

Lastly, urban infrastructures are complex systems containing many processes and interdependencies; the measurement of resilience requires continuous reflection for making decisions according to changing basic and environment conditions.

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Florian Brauner studied Rescue Engineering with focus on Civil Protection. For several years, he has been researching the different effects of security measures in critical infrastructures such as socio-technical consequences. He developed a model to assess the risks of terrorist threats for large scale infrastructures. Today, his research focuses on "smart" resilience approaches to improve risk and crisis management. He currently works as a postdoctoral research associate at the University of Wuppertal, Institute for Public Safety and Emergency Management and as security expert for Critical Infrastructures.

Marie Claßen is a research assistant at the faculty of Safety Engineering of the University of Wuppertal focusing on resilience indicators in urban areas. In 2016, she graduated with a Bachelor degree in Sociology and started afterwards her Master in Sociology both at University of Wuppertal. As a scholarship holder of the Deutschlandstipendium, she gets supported by the German government and the company Vorwerk. She gained educational experiences abroad during her High School Year in Queensland, Australia, and her Erasmus year in Italy.

Frank Fiedrich studied Industrial Engineering and received his PhD from the Karlsruhe Institute of Technology, Germany, where he worked on Decision Support Systems and Agent Based Simulation for disaster response. From 2005 to 2009 he was assistant professor at the Institute for Crisis, Disaster, and Risk Management ICDRM at the George Washington University, Washington DC. Since 2009 he is chairing the Institute for Public Safety and Emergency Management at the University of Wuppertal. His research interests include the use of information and communication technology for disaster and crisis management, societal, organisational and urban resilience, interorganisational decision making, critical infrastructure protection, and societal aspects of safety and security technologies. Prof. Fiedrich is honorary member of the International Association for Information Systems in Crisis Response and Management (ISCRAM) and member of the scientific advisory council of the German Committee for Disaster Reduction (DKKV).