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Methodological and Ideological Options

# Ecology-related resilience in urban planning – A complex approach for Pécs (Hungary)

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ABSTRACT

The aim of this paper is to introduce an urban planning methodology which enables planners to select projects, which fit the main goal of the city and develop a resilient strategy structure, based on the selected projects. The planning process is demonstrated by the development of a resilient city strategy – in this case, by the city of Pécs.

The main goal of a city (in the case of Pécs: to become a sustainable city) determines policy directives and the functional areas involved, whilst the strategic goals and sub-goals of the functional areas influence projects. These projects generate impact flows, which provide the basic data for Ecological Network Analysis to measure the basic resilience of the strategy structure.

It is known from ecological systems that neither totally redundant nor highly efficient systems are sufficiently resilient. ENA allows an optimisation procedure to be undertaken. As a result, a complex iterative model is devised, suitable to elaborate a resilient strategy structure.

This paper shows that efforts to achieve sustainability can be used to organize resilient structures. The study applies this locally – where city strategy pursues sustainable aims – and globally, where existing global knowledge will be organized into a resilient structure.

## 1. Introduction

Rockström et al. (2009) identified nine planetary boundaries, three of which man has already violated (climate change, the rate of biodiversity loss, and the level of interference with the nitrogen cycle). Their results intensified the sustainability debate: How can we ensure the safety of mankind's activity on our planet?

The fact that Ecological systems' main feature is resilience explains why sustainability and resilience are interconnected in published papers; to the point where the term ‘resilience’ is interchangeable with ‘sustainability’ (Saunders and Becker, 2015, Arora-Jonsson, 2016).

Resilience can be defined as “The ability to resist and respond to a shock (internal or external) and recover once it has occurred …” (Annarelli and Nonino, 2016, p.2). Folke et al. (2010) integrate the main elements of resilience thinking: resilience, adaptability and transformability as a systems behaviour and dynamics, which also indicate that the term “resilience” is not necessarily connected to ecological systems. Rochas et al. (2015, p. 359) conclude that there are universal features of resilience, namely that a system is resilient if it is diverse, redundant, efficient, autonomous and strong in its crucial components. These definitions suggest that resilience is a more general term, than sustainability.

The origin of the notion of resilience is ecology, where there is little doubt that well operating ecological systems work resiliently. However, ecological systems are sustainable in the long run; ecological systems and sub-systems are harmonised, since higher systems emerge if subsystems need this (Cf. ‘ecological hierarchy’ in Meadows (2008, pp. 82–85)). In socio-ecological systems this sustainable, harmonising element is not given, even, as it is seen e.g. from Rockström et al. researches, the opposite seems to be valid. We define this harmonisation element as a systems behaviour, which contributes to (or at least does not endanger) the safe operating place for the Planet's living systems, and name this behaviour as *sustainability element*.

A misfit of a sub-system is not obvious, as long as the carrying capacity of the main system is greater than the damage due to the misfit of subsystems. An agrarian production system could fit into its larger environment (and be resilient) if it can deliver products in large quantities and good quality, independently of the fact that they used chemicals and pesticides which are not in harmony with ecological systems. Therefore, in many cases a system can be resilient and at the same time not sustainable: a misfit within the planet's main system.

Ecological Network Analysis (ENA) measures the level of resilience in an ecological system by examining the physical flow of materials and energy. It examines and measures *structural resilience* which – if the

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system proves to be resilient – inherently means sustainability in ecology terms. In the case of socio-ecological systems, resilience is not equal to sustainability, because the *sustainability element* is not necessarily present.

This study focuses on *urban resilience planning*, the resilience of the structure of the city strategy, and provides a method for creating a *structurally resilient strategy*. ENA also provides the methodology for creating a resilient structure (an optimization procedure), which is appropriate to plan a resilient strategy. Additionally, this method is used to unify sustainability efforts (as the sustainability element) with resilience in a way that it organizes these efforts into a resilient structure. The sustainability element is provided in two ways:

1. First, locally, the main goal of city strategy and related policy directives pervades the project generations and experts select sustainable projects;
2. Second, globally, existing published sustainability efforts (research and cases) are the source of the sustainability element.

In both cases these efforts will be organized into a resilient structure.

### 1.1. Resilient Cities

The resilience of cities is a relatively new topic. In fact, the need for the conceptual term emerged in the aftermath of the attack - invariably referred to as '9/11' - on New York's World Trade Centre in 2001 (Mendonça and Wallace, 2015, Annarelli and Nonino, 2016), although, the actual origin is earlier, in the 1990s (Lu and Stead, 2013). Foster (2006) asserts that a region can achieve an *intentional resilience* if both the

- *preparation* (*assessment and readiness*) and
- *performance* (*response and recovery*) resilience are strong in the region.

Foster, in addition, suggests that resilience can, in fact, be developed - which also supports the use of ENA for urban planning (as in the *preparation phase* of a regional development project).

Recent developments clearly show that there are different forms of crisis which are likely to occur, such as an economic crisis or climate change, and one specific significant form is the wide-spread and serious increase in the urban population - which inevitably increases the demand for products and services, with increasing environmental and social impact on the hinterland. This is the case not only in China (Zhang, 2013), where the size of cities in itself indicates a significant impact, but also in Europe (see 'Five UK Cities' in Minx et al., 2011). According to Foster's categories, the first part of the *preparatory* phase (the *assessment*) should disclose all the changes expected, whilst the *readiness* of the region (the second part of the phase) should be elaborated for these changes. Rochas et al. (2015) produced resilience assessments for cities and detailed how to select the most effective recovery strategies related to energy supply reliability and to the sustainable use of resources. Liu et al. (2011) analysed the structure and functioning of an urban system and undertook considerable research into 'urban metabolism', which is one of the key terms in similar research (Zhang et al., 2015a). Both examples refer to the *assessment* phase, and the latter also indicates that the structure of the region is a critical element of resilience. In order to prepare a region or city for change, for adequate *readiness*, the structure should be planned carefully, and one well known means of this is *urban planning*.

The structure of a city can be influenced by the city's strategy, and this strategy should focus on *intentional* resilience, as a consequence of which future projects would create the necessary (physical and non-physical) infrastructure.

There are numerous alternative approaches to regional development. On a European political level a guideline for an Integrated Urban Development Strategy (IUDS) was announced in the European Union (Lisbon Strategy, Leipzig Charter). However, the environmental part of the IUDS is rather weak, and – in the case of Hungary – the country level applications were segmented and did not reach the expected results (Suvák, 2010). A recent study further analysed the most important features of cities which are regional centres in Hungary. They state that stakeholders hardly have a chance to form the processes; only a few of them can participate in the decision making (Bajmócy et al., 2016, p.97).

There are several research projects referring to the transformation of cities. Xue (2014) argues that existing solutions are not necessarily appropriate: e.g. the idea of eco-villages neglects the existing urban structures, therefore, does not represent proper solutions. A few of the other relevant researches are the following: Camagni et al. (1998) states that there are three main fields to intervene, namely: technology, territory and lifestyle. Ackerman (2004) sees the co-governance as a crucial point in the transformation. Pretty (2011) suggests ecoculture, where place-based connections with the environment would improve the city's resilience. Arora-Jonsson (2016) argues that resilience itself has its own culture, and as such, it contributes to the production of the necessary transformative knowledge. Alternative transformative approaches will be further addressed in Section 7.3.

### 1.2. Location

Pécs is a medium-sized city with approximately 150,000 inhabitants today, located in the southern part of Hungary. The structure of the city was strongly influenced by coal-mining (Hajnal et al., 2009). Between the 1950s and the 1980s, the city's population nearly doubled, mainly due to the mining industry. When the coal-mines were closed at the end of the century, the main driving force of the city was lost, but the huge infrastructure remained, waiting for re-purposing, refurbishment and/or a final replacement. Since Pécs has one of the largest universities in the country, the cultural element was dedicated to becoming such a driver. The culture in this case means those expressive forms of culture (e.g. theatre, music, arts), which are able to generate revenue for the city. This new orientation is further promoted by the fact that Pécs was always a multi-cultural city – a type of melting pot of different values. Hungarians, Croatians and Swabians, still live comfortably together here. A significant event occurred in 2010, when Pécs was selected to be a European Capital of Culture along with Essen and Istanbul, which further stimulated some renewal in the direction of culture: Renovated public spaces, streets, squares and neighbourhoods, new cultural centres, a concert hall, a new library and science centre and a 'Cultural Quarter' were planned and built.

The local authority of Pécs also voiced a request for a sustainable energy- and for a city strategy. Both have been produced in accordance with the requirements of the local government, based on sustainability principles.[1]

The model of the city's sustainable energy strategy is available now; a simulation, based on this strategy was developed, which integrates the proposals of the energy strategy, simulating the energy system at an hourly rate (Kiss, 2015).

#### 1.2.1. The Structure of the Paper

Fig. 1 depicts the urban resilience planning process. After the *Introduction* (Section 1), *Methodology* (Section 2) is discussed. *Goal-hierarchy and the basic building blocks* (Section 3) describes the main goals of the city, policy directives and selected functional areas with their main

[1] Both are in Hungarian. The city strategy is available at http://gov.pecs.hu/download/tajekoztatok/fejlesztesi_koncepcio/pecs_telepules_fejl_strat.pdf (20/4/2017); the energy strategy is at: http://gov.pecs.hu/download/tajekoztatok/strategia/pmjves.pdf (20/4/2017).

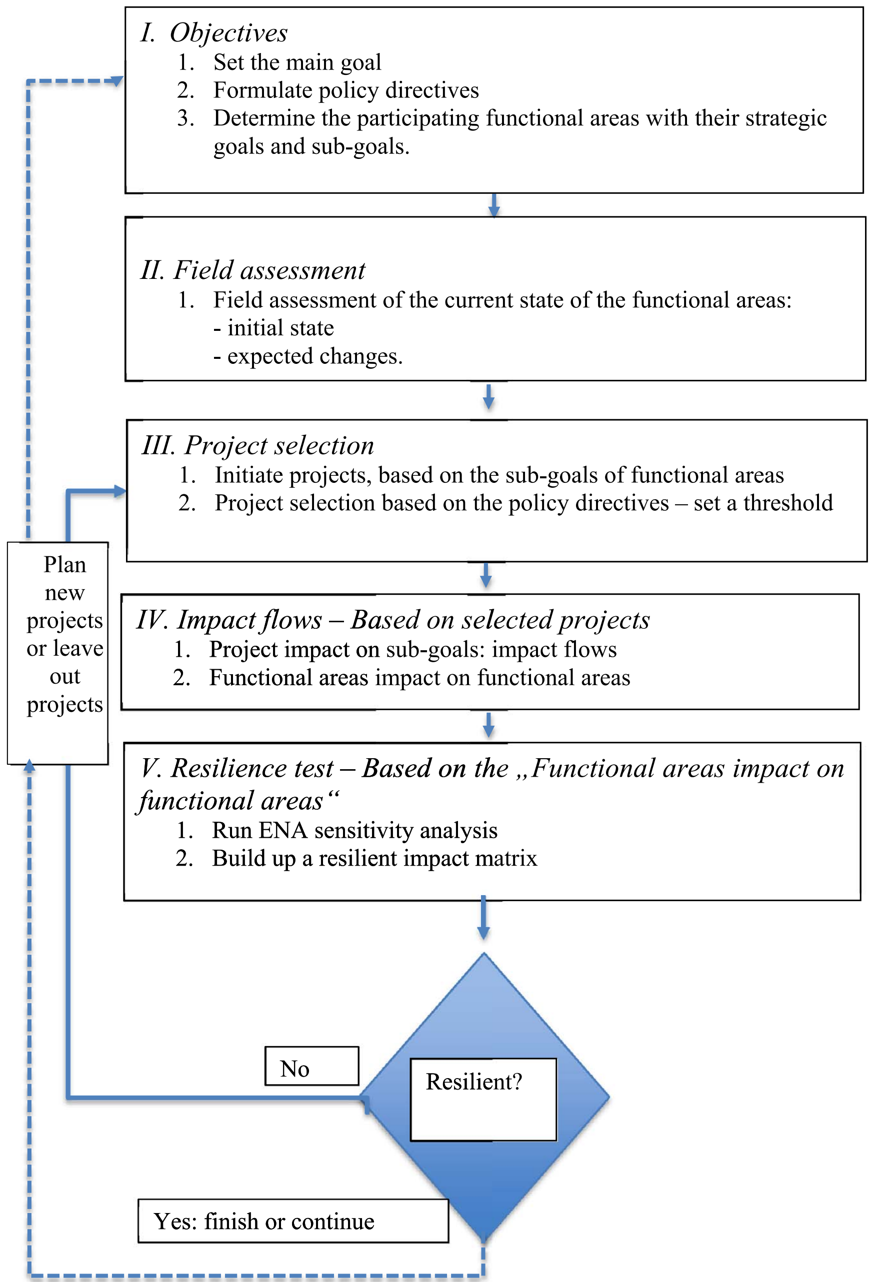


**Fig. 1.** Summary of the urban resilience planning process.

and sub-goals. *Field Assessment* is discussed in Section 4 with the current state and expected changes of the functional areas. In *Project Selection* (Section 5) *thresholds* are established in order to select those projects which fit the policy directives. *Impact Flows* are estimated in Section 6 to create an impact matrix, which will be the basis for the resilience test. The *Resilience Test*, an optimal structure of projects' impacts and attempts to involve the current sustainability efforts into a resilient framework are described in Section 7. Other issues, such as limitations and further development possibilities discussed in Section 8 and the *Conclusion* closes the study. The *Appendix* describes two more useful spreadsheet model-extensions.

## 2. Methodology

The elaborated urban planning method uses two types of modelling tool: spreadsheet models for urban planning in general and ENA methodology for testing and developing the structural resilience of the plan. Data and basic calculations need a static, linear approach, and so a spreadsheet model is a satisfactory solution. Spreadsheet models were mainly used for regional developments in the '90s (see e.g. Brail et al., 1993), although one of the modellers' basic rules is that one must use the simplest modelling technique which is appropriate for the purpose. The *Resilience test* block uses ENA.

### 2.1. Brief Introduction to ENA Methodology

Ulanowicz (see e.g. Ulanowicz, 1997, 2004, Goerner et al., 2009 or Ulanowicz et al., 2009) has a main contribution to the development of ENA, such as sustainability index and sensitivity analysis. ENA is a widespread methodology used not only for ecological systems, but also for economic (Zhang et al., 2015b) or regional economic systems (Huang and Ulanowicz, 2014). Bodini et al. (2012) examined cities as ecosystems. Energy consumption of cites is also modelled (Zhang et al., 2015b) and urban metabolism is also examined in similar models

(Zhang et al., 2015a). The ENA methodology is available in R also, known as *enaR* (see Borrett and Lau, 2014).

Ulanowicz et al. (2009) summarize the basic calculations for the ENA methodology used in this paper. The material flow of the system can be illustrated with a matrix ($T$), and the relationships between system elements ($T_{ij}$), where the total throughput of the system is $TST$. The ratio of one flow element to $TST$ is:

$$p_{ij} = T_{ij}/TST \quad (1)$$

The total capacity of the system, including the inherited opportunities, is calculated from $p_{ij}$ values:

$$C = -k\sum p_{ij}\log(p_{ij}) \quad (2)$$

The cohesion level (the already bounded part) of the system ($A$) is calculated as follows:

$$A = k\sum p_{ij}\log(p_{ij}/p_{i.}p_{.j}) \quad (3)$$

where the summation refers to both $i$ and $j$, and the dot means also a summation by the index, where the dot is situated.

The remaining part, $\Phi = C - A$ is the reserve, where the system can flexibly react to disturbances. The system's efficiency level follows from the factors above:

$$\alpha = A/C \quad (4)$$

If there is a high level of (bio)diversity, but a lack of relationships between the elements, there is no resilience in the system, the value of A is very low, and the system is very redundant: the system has many reaction opportunities, although it does not have the necessary operating efficiency. On the contrary, either in a case of only a few factors or high level of diversity, if the system is highly efficient, firmly bounded by mutual relationships, no place for change, the value of $A$ is very high, close to the full capacity ($C$). In the case of a full efficiency $\alpha$ is 1 – mainly a fully automated system with zero reaction opportunities. The system is not resilient in either case. In maturated ecosystems the $\alpha$ values are around $1/e$, they are fully resilient systems (Ulanowicz et al., 2009, Goerner et al., 2009). A "proper" resilience indicator is also elaborated (*Fs*). *Fs* has its maximum value of 1 (the maximum resilience of the system), when the $\alpha$ value is $1/e = 0.368$. In order to obtain a proper resilience indicator, this value should be transformed, where the values are between 0 and 1 (Ulanowicz, 2014):

$$Fs = -e\alpha^{\beta}\ln(\alpha^{\beta}) \quad (5)$$

where

$\beta$ = a coefficient, which is served to adjust the level of optimality (this way, the optimal value can be different from $1/e$).

A sensitivity analysis methodology is also developed in ENA. The analysis refers to each flow element in regards to the whole system. It shows that in order to get an optimal structure, in which direction the magnitude of the flow element should change. Sensitivity analysis is based on the robustness of the system, which can be expressed in the following way: $R = Fs * TST$. $R$ is differentiated by the $T_{ij}$-elements (Ulanowicz, 2014):

$$r_{ij} = \frac{\partial R}{\partial T_{ij}} = Fs + \frac{Fs'}{C}\left\{\ln\left[\frac{T_{ij}TST}{T_{i.}T_{.j}}\right] + \alpha\ln\left[\frac{T_{ij}^2}{T_{i.}T_{.j}}\right]\right\} \quad (6)$$

where

$$Fs' = -e\beta\alpha^{\beta-1}[\ln(\alpha^{\beta}) + 1] \quad (7)$$

Individual $r_{ij}$ values show in which directions it is worth developing the relationships between elements in order to achieve a robust system, an optimal $\alpha$ or $Fs$ value. Based on the $r_{ij}$ values, the $T_{ij}$ values are increased or decreased to be closer to the optimal $\alpha$ value. City planners' experiments with some alternative $\beta$'s will be useful to explore whether other optima might be preferable for use in city planning. After an iteration process, an optimal system can be achieved. This method will be used in formulating a resilient city plan.

The resilient structure, provided by ENA, matches the integrated resilience thinking elements (Folke et al., 2010). An optimal $\alpha$ value indicates a structure where there is enough redundancy to adapt to a new situation, or to absorb disturbances (Walker and Salt, 2012). Transformational needs might also become necessary in case of the emergence of a new connection or a significant change of the magnitude of one of the connections. The content of cells might also need transformation, as will be discussed in Section 7.

### *2.2. Evaluation Space*

The whole system works with standardized values. A minimum and a maximum value are needed to prepare the space for the "wholeness". These values in this system are −5 to 5. −5 means the worst, and 5 the best state of the functional areas. This range of 10 provides the space for estimated values (current state, changes), which are also standardized in accordance with this value scale. Delphi methodology can be used to ask for expert opinion for parameter estimate of different projects, involved in the implementation of the city strategy. The Delphi method is used for transforming expert opinion into useful input parameters. Tapio (2002) used the method to ask experts to give estimates to the probable and the preferable futures of some key variables for 1997–2025, which is practically the same data collection procedure which this paper needs.

This study uses parameters estimated by the strategy planners since the budget for strategy development was restricted and did not allow for the application of the Delphi method with appropriate sample size. Therefore, the concrete values in the study are rough estimates and mainly used for understanding the planning methodology.

## 3. Goal-hierarchy and the Basic Building Blocks

In traditional city strategies a heavier emphasis is visible on spatial planning (Freestone, 2015), overlooking certain organizational issues. However, this approach is, by far, insufficient in our rapidly changing global environment. Instead, the strategy should lead to an integrated urban system which is efficient and can properly utilize resources in order to be resilient in response to disruptions (Kharrazi and Masaru, 2012). Appropriate functional areas should be selected in order to integrate them into a unified, well-operating system. Architecture, energy and transportation ensure the infrastructure. The main goal – sustainability – traditionally has three pillars: environment, society and economy. Additionally, researchers prove that local government has a crucial role in the sustainability efforts of a city (Ackerman, 2004). Therefore, the selected areas are the following:

- *Natural environment* (*Nature*) provides the basis for our urban settlement. This factor is usually eliminated from city strategies; however, the importance of this area is increasing (Votsis, 2017). Odum (1989) also treated the subsidies of the natural environment of cities in detail.
- *Society* – people, communities living in the city are the main stakeholders, since the city is for and by them. However, they use their environment intensively (see e.g. the socio-ecological studies (Barles, 2015)).
- *Economy* is sovereign in what we might term the 'mental models' of our modern age. However, this is only one – albeit important – element and it is a significant socio-economic driver of environmental pressures (Yu et al., 2015).
- *Architecture* is the traditional element of formulating a city strategy and is still very important (Freestone, 2015).
- *Government* is generally the local authority, where the leadership should understand the integrated nature of the city. The social element is crucial in this respect. A proper framework should be formulated to work "*with people*", not only "*for people*"; *co-governance* is

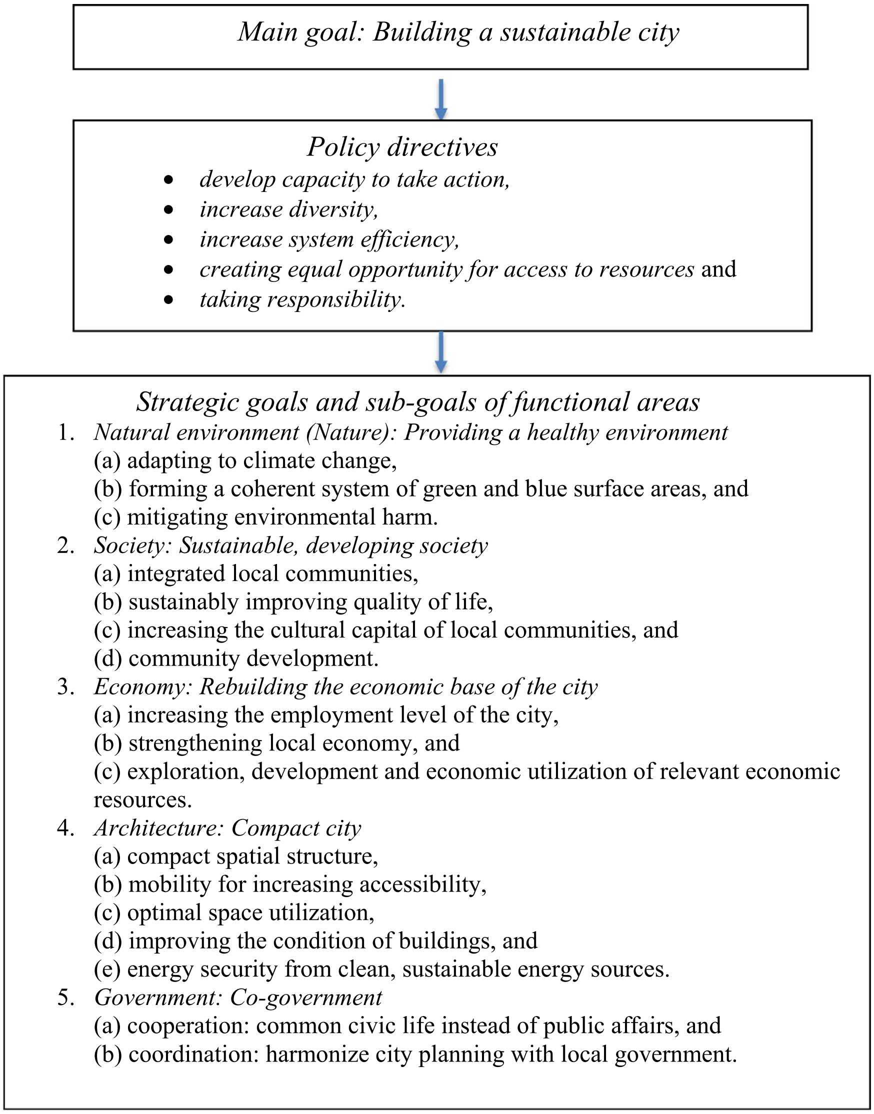


**Fig. 2.** The goal-hierarchy of the strategy.

"the best way to tap into the energy of society" (Ackerman, 2004, p. 447).

*Energy*, energy security, is one of the most sensitive questions for the future (Papastamatiou et al., 2016) - together with *transportation*. These two areas do, of course, overlap, and, since they are responsible for the majority of greenhouse gas production (Saboori et al., 2014), drastically improving their resource use is an urgent and difficult task and should be seriously considered in any city's strategy. *Energy* and *transportation* are here integrated into *Architecture* for the sake of simplicity.

The goal-hierarchy is shown in Fig. 2. The main goal is to meet the requirements of the local authority. The strategic goals and sub-goals, policy directives are determined specifically in Pécs by the city planners, and they have had some influence on project generations. However, the goal-hierarchy is general enough for universal application. Basic policy directives are derived from the original main goal of building a sustainable city and policy directives support the main goal, which (together) demarcate the goal set of the functional areas (strategic goals). These goals are subdivided into sub-goals, which are able to govern relevant projects (operational level). These projects should be in harmony with the policy directives, the strategic goals of the functional areas and with each other also.

The selected five functional areas will be the basis of the analysis in order to keep the structure concise and clear, and so to understand the underlying methodology. On the other hand, these areas are rather vague and leave room for a variety of ideas. *Architect* for example embraces energy and transportation also; therefore, if a project is generated in *Architect* (see Section 7), it can also be a renewable energy project or a park development. This is the main reason why "projects" are also handled so broadly. For a more detailed analysis, broadening the examined areas is possible (e.g.: separating energy from architecture and working with six functional areas).

## 4. Field Assessment

Data were to be standardized for use in the ENA, and so the question posed had to reflect this. Experts were asked to estimate the current state of the functional areas on a −5 to 5 scale. Firstly, the current situation of the areas was estimated, following which the expected yearly change in these areas was sought, on the assumption that no intervention occurred. (These values should also include all earlier effects). The request then posed was:

> "*Please estimate the current state of the areas in the table below from −5 to 5, where −5 is the worst and 5 the best. Also, estimate the possible yearly change if no intervention were to occur. As an example: If the current state of one area is −2 and you think that in one year it would be −3 (with no intervention) then the value of the change is −1*

**Table 1**
Estimate of the current state – natural environment with its sub-goals.

| | Natural environment | | | |
|---|---|---|---|---|
| | Nature | Providing a healthy environment | | |
| | Average value | Adapting to climate change | Formation of a coherent system of green and blue surface areas | Mitigation of environmental harm |
| Current state (− 5 to 5) | − 2 | − 3.1 | − 1.1 | − 1.8 |
| Current state – expected change | − 0.1 | − 0.15 | − 0.05 | − 0.1 |

*(unit)*."

In this way, the starting points of the functional areas, which are the most important from a city strategy point of view, were set. Both the starting values and the possible changes are estimated. Table 1 (below) shows the estimates relating to the functional areas, including sub-goals in the case of the *Natural environment*. Note that the yearly change can be extended into short, medium and long timeframes to get a clearer picture of the nature and strength of possible changes.

The table shows the experts' opinions of the current situation and of the probable change. Average values for the functional area (*Natural environment* in this case) from the sub-goals are calculated: − 2.0 for the current state and − 0.1 for the expected change. The current state of *Natural environment* is worse than average (below zero) and will decline further if no intervention should occur. '*Adapting to climate change*' (a sub-goal) has a strong negative value (− 3.1), meaning that the city is not prepared at all for this. The corresponding − 0.15 in the second row means that this situation is worsening and in one year the state of the area would have a value of − 3.25.

Table 2 below depicts the estimated initial values and the expected changes for all the functional areas.

Values in the table show that – apart from *Architecture* – each functional area is in a weak condition, which will worsen if there is no intervention.

## 5. Project Selection

Project plans were elaborated to cover the sub-goals (Fig. 2.) In the following the general term "project" is used instead of the full name of the projects. There is a fourfold reason: These projects are the product of a limited selection (the purpose of the selection was mainly to demonstrate the methodology); results could be misleading due to the sample size of the experts; the process can be easily understood without naming the projects and some projects are strictly local and so meaningless to outsiders.

### 5.1. Thresholds of Policy Directives

If a planned project does not fit the policy directives, it should not be carried out, even if it is a profitable, multifunctional, effective project. One example is Cotacachi (Ecuador), where a mining investment was refused and eco-farming has been developed (Oliver et al., 2003), since the latter was more in harmony with the strategy.

**Table 2**
Estimate of current values for all functional areas.

| | Nature | Society | Economy | Architect | Govern. |
|---|---|---|---|---|---|
| Current state (− 5 to 5) | − 2 | − 3 | − 3.67 | − 0.6 | − 2 |
| Current state – expected change | − 0.1 | − 0.2 | − 0.2 | − 0.08 | − 0.2 |

To filter out the projects which do not fit the policy directives, experts can evaluate the projects from this perspective, and the Delphi method is used to formalise their opinions. Table 3 below shows the results of the projects' impact on policy directives. The request is then:

"*Please estimate the direct yearly impact of the given project on the policy directives in the table below. If the project is fully implemented, how will it directly influence the fulfilment of the policy directives? Please use − 5 to 5 as lower and upper limits and ignore non-significant impacts. As an example: Considering the range of 10 (− 5 to + 5), a project would contribute to the increase of diversity with half a unit yearly, then the value of the change is 0.5 (unit)*."

There are seventeen projects from the five functional areas. Projects 1–2 are environmental, Projects 3–5 are social, Projects 6–9 are economic, Projects 10–13 are architectural and Projects 14–17 are governmental by nature. The values in the columns of policy directives are average values from the experts' individual assessments. The *Average impact* column contains the grand mean impact of the different projects on policy directives for every project. The last row shows the average impacts of the projects on policy directives for each directive. These latter values indicate an equal distribution of impacts on policy directives (with roughly equal values), although perhaps marginally stronger in terms of the capacity development.

Decision makers can determine *threshold values*. If the value for the individual project exceeds the threshold value, the project is selected. A simple solution is to use the grand mean value (in our case: 0.222, see Table 3, lower, right hand corner), or – if the decision makers would like to implement more projects, as is the case in this study – to set the threshold value one standard deviation under the grand mean (in our case: 0.117) (Table 4).

Also in our case, the use of the grand mean excludes 10 projects. In order to select more projects, the latter threshold is used, with which all projects above 0.117 are kept in the system. In our case this means that all the projects are selected, since the "weakest" project (Project 3) has a value of 0.119.

## 6. Impact Flows

A City strategy with proposed projects is created to change the current situation, to make the necessary interventions. Therefore, the direct impact of a proposed project on the sub-goals should be estimated in order to determine the effect of the proposed projects on the strategy. With these estimated impact values, links will be created between the functional areas. Experts estimate the impacts of the projects and. so the request to the experts is:

"*Please estimate the direct yearly impact of the given project on the sub-goals in the table below. If the project is fully implemented, how does it directly influence the fulfilment of the sub-goal yearly? Please use − 5 to 5 as lower and upper limits and ignore insignificant impacts. As an example: Considering the range of 10 units (− 5 to 5), a project would contribute to "Adapting to climate change" with a whole unit yearly, then the value of the change is 1.0 (unit)*."

The phrase "fully implemented" means that the project is completed 100% in accordance with the intended objective. Appendix A contains a method for weighting incomplete projects, although this is not applied here.

With the help of this matrix (projects impact on sub-goals) city planners can recognise whether all the sub-goals are covered by projects. The ratio of the coverage of functional areas and their sub-goals can be checked in this way. Appendix B describes a method which determines the ratio of what percentage of the sub-goals is covered by a project. The sum values provide an opportunity to select the projects with the highest impact to implement. The *Sum* and *Rank* columns of

**Table 3**
Estimate of the impact of projects on policy directives.

| Projects | Capacity to act | Increase diversity | System efficiency | Creating equal opportunity for access to resource | Taking responsibility | Average impact |
|---|---|---|---|---|---|---|
| Project 1 | 0.28 | 0.35 | 0.24 | 0.38 | 0.22 | 0.295 |
| Project 2 | 0.19 | 0.4 | 0.17 | 0.35 | 0.28 | 0.278 |
| Project 3 | 0.12 | 0.1 | 0.11 | 0.14 | 0.14 | 0.119 |
| Project 17 | 0.29 | 0.35 | 0.42 | 0.43 | 0.24 | 0.346 |
| Average impact | 0.24 | 0.196 | 0.216 | 0.23 | 0.228 | *0.222* |

The value in italics is the grand mean of all the values in the table.

**Table 4**
Calculation of threshold values.

| Statistics | Values |
|---|---|
| Grand mean | 0.222 |
| Standard deviation | 0.105 |
| Grand mean – standard deviation | 0.117 |

**Table 5**
Estimate of the impact of projects on functional areas.

| | Nature | Society | Econ. | Arch. | Gov. | Sum | Rank |
|---|---|---|---|---|---|---|---|
| Project 1 | 1.097 | 0.344 | 0.296 | 1.687 | 0.611 | 4.037 | 5 |
| Project 2 | 0.522 | 0.736 | 0.094 | 1.382 | 0.300 | 3.036 | 8 |
| Project 3 | 0.338 | 0.574 | 0.319 | 0.345 | 0.151 | 1.728 | 17 |
| Project 17 | 0.737 | 1.146 | 0.992 | 1.567 | 0.561 | 5.005 | 1 |
| Sum | 6.214 | 11.326 | 10.403 | 16.224 | 8.715 | | |
| Rank | 5 | 2 | 3 | 1 | 4 | | |

Table 5 (already a "compressed" matrix) shows the total impact and the rank of projects.

The detailed matrix can be compressed in more ways also. Firstly, the sub-goals of functional areas can be compressed to see the impact of the projects on these areas. The more sub-goals a project has, the greater is the impact of the functional areas. Table 1 comprises data from *Nature* and has its three sub-goals. Sub-goals are separated from each other (otherwise they would be one sub-goal), although, overlapping necessarily exists. Therefore, a summation is applied, accepting the possible distortion of the overlapping effects. Table 5 shows these values. This table's last two rows (*Sum* and *Rank*) can be used similarly to the *Sum* and *Rank* columns: they show the total expected impact on functional areas and the rank of functional areas by impact.

Another type of compression is possible: rows with projects could be summed up by functional area. The more projects implemented, the higher is the effect, although some overlapping is also possible here. In this case the first two rows, Project 1 and 2, would give *Nature's* impact: 1.62. Planners can check the impact of functional areas on different sub-goals with the help of this table.

Finally, both types of summation can be applied to see the impact of all the projects originating from functional areas on functional areas. This latter matrix is shown below. This matrix shows the impact flows between the functional areas, which is the same in logic as the carbon flow in ecological systems (which is a basic example of the application of ENA), and so this can be the basis for ENA – see the next section.

This table demonstrates the flow between functional areas. The interpretation of the table is the same as for an input-output analysis. The value of 0.8717 in the first column – fourth row is: The *Architecture* functional area impacts on the *Nature* area by 0.8717. This value also has another meaning: *Nature* is impacted by *Architecture*. The summation values show that *Government* impacts on most other areas (16.8), the *Architecture* has the biggest impact from others (14.31).

The spreadsheet methods introduced here provide a reliable tool for decision makers. Projects, in harmony with the policy directives - and with proper impact on other projects and functional areas – can be selected. However, the resilience of the structure of the city strategy, displayed in Table 6, can also be examined. This is the task of the next section.

**Table 6**
The full impact matrix - the impact of projects of functional areas on functional areas.

| | Nature | Society | Econ. | Arch. | Govern. | Sum. |
|---|---|---|---|---|---|---|
| Nature | 1.6206 | 1.0806 | 0.3911 | 2.884 | 0.9119 | 6.8881 |
| Society | 0.6599 | 2.1965 | 1.0260 | 1.3688 | 0.9504 | 6.2016 |
| Economy | 0.7981 | 2.4568 | 3.2235 | 1.5543 | 1.8036 | 9.8362 |
| Architecture | 0.8717 | 2.4105 | 1.7521 | 3.8862 | 2.3225 | 11.2431 |
| Government | 2.2639 | 3.1822 | 4.0110 | 4.6166 | 2.7270 | 16.8006 |
| Sum | 6.2142 | 11.3265 | 10.4036 | 14.3099 | 8.7154 | |

## 7. Application of ENA - Discussion

The fact that a selection of projects, capable of satisfying the goals, is available does not mean that they will properly work together. Fully matured ecological systems – which can be considered as exceptionally resilient systems – are redundant and have an appropriate level of efficiency for a healthy operation (Ulanowicz et al., 2009). Therefore, a wide variety of projects – the system has a high level of redundancy – does not necessarily ensure the appropriate level of efficiency, and so the efficiency level should also be examined to prepare a good strategy. Foster (2006, p.19) emphasises both factors (the redundancy built into the system and the effectiveness of readiness skills) as the quality of *readiness*. Goerner et al. (2009) used this method in their ecological example to measure the carbon flow in the ecosystem of the cypress wetlands of South Florida. The carbon flows between populations were examined. Ecologists created a matrix where the selected populations (prawns, turtles, large fish, snakes and alligators) were displayed both in rows and columns and the matrix elements were the carbon flows between populations.

In the same way, physical flows (e.g. urban metabolism) can also be measured and illustrated (Bodini et al., 2012). However, a city's everyday life comprises much more than the physical processes; it also includes local government activity, the social network, etc. In the case of a strategy, there is no material flow, but only policy directives, sub-goals and expected impacts. Hence material (carbon) flows will be replaced by *impact flows*, estimated by experts.

At this point ENA is used for testing the resilience of the structure of the strategy with the methodology used in ecosystems by ecologists. The impact matrix of the selected projects will be tested with the resilience indicator and an optimal impact structure will be formulated with help of the corresponding sensitivity analysis, as is discussed in Section 2.

In order to make a socio-ecological system – a city strategy in this case – sustainable, it is advisable that the resilient structure be added to the sustainability efforts. In Section 7.1 the sustainability element is created locally. The main goal – building a sustainable city - the related policy directives and sub-goals influence the projects, which are ultimately the realisations of the strategy. Additionally, these projects are filtered by local experts, and this further secures the real sustainability of the content. In Section 7.2, we offer some pieces of practical advice and 'rules of thumb' to ease the work of planners, designing resilient and sustainable systems, whilst in Section 7.3, we utilize sustainability efforts which have been globally proved and related research to create and elaborate a resilient structure.

### 7.1. A Local Application

In the original ENA applications, the material (e.g. carbon) flow pathways and magnitudes in natural ecosystems are used to develop a measure of network efficiency (or resilience). Here, in the application to urban resilience, carbon flows are replaced by impact flows; therefore, Table 6 can be used as a matrix for estimating the resilience of the structure.

Table 6 summarizes the impact of future investments (projects) on the city. One of the big differences between trophic chains and estimated project impacts is that ecology regulates the relationships properly (who eats whom), but project impact estimates can be arbitrary. The result is as expected: the current strategy is highly redundant, the α value of this system is 0.016 ($Fs = 0.18$) and a not regulated "everything is possible" impact structure is created. The optimisation procedure - based on the sensitivity analysis below - helps to get a resilient, more focused structure with fewer connections. The first step (as described in Section 2) is to run a sensitivity analysis, calculate the $r_{ij}$ values (6), where the values above (below) 1.0 indicate that an increase (decrease) is needed in the value of the cell in order to be closer to an optimal structure, where the resilience indicator ($Fs$) is 1.0 (or $\alpha$ value is $1/e$). Negative values can be handled as attempts to remove those connections from the structure. New $T_{ij}$ values (suggested impacts) will be calculated accordingly to the $r_{ij}$ values afterwards (e.g. $r_{ij} = 0.9$ indicates a 10% reduction of the $T_{ij}$ value). Table 7 below shows the result of the $T_{ij}$ values after the first optimisation step.

In this new table the figures with negative values will be removed to create the starting position to the second optimisation round. The process is repeated until the $\alpha$ value reaches $1/e$: 0.368. This way an optimal impact matrix is created, based on the generated and selected projects. The optimum has been reached automatically, applying the $r_{ij}$-values in each round.

In the following, the interpretation of a resilient solution will facilitate our understanding of the main characteristics of the structure - which itself will allow for its application to individual cities.

These elements are different from those in the full impact matrix in Table 6, however; only those cells remained, where originally there were high impact values. There are 1, 2 or 3 connections in each row and column. In Table 6, there were only high impact connections in the *Government* row, which are either removed or significantly reduced. This optimal, resilient structure concentrates on a limited number of connections. However, this limitation does not only leave fewer connections to barely ensure operational efficiency; but the number of connections is large enough for a proper buffer capacity.

*Architecture* (see the explanation of this broad term in Section 3) still has the highest impact (4.756). This is due to the area's own development (1.891 – e.g. the capacity development for building or restoration); a significant part comes from *Nature* (2.426 – e.g. building on common green areas for housing estates or planting living fences on the verges of motorways); and the smallest part (0.404) derives from government, e.g. regulates the energy efficiency of buildings. *Architecture* impacts – apart from its own development (1.891) – on *Society* (0.072 – e.g. building public housing); and *Government* (0.946 – e.g. building a community intermodal transportation hub).

**Table 7**
New $T_{ij}$ values after the first optimisation step.

| | Nature | Society | Econ. | Arch. | Gov. |
|---|---|---|---|---|---|
| Nature | 2.2012 | − 0.6688 | − 0.9659 | 2.5163 | − 0.4047 |
| Society | − 0.1450 | 2.1833 | − 0.3598 | − 0.5494 | − 0.1488 |
| Economy | − 0.5934 | 0.7741 | 3.2884 | − 1.6325 | 0.3854 |
| Architecture | − 0.7232 | 0.0389 | − 0.7900 | 1.9711 | 1.0552 |
| Government | 0.6332 | − 0.6918 | 1.6365 | 0.2968 | − 0.0321 |

**Table 8**
Optimal structure, iterated by the results of sensitivity analysis.

| | Nature | Society | Econ. | Arch. | Gov. | Sum |
|---|---|---|---|---|---|---|
| Nature | 2.028 | | | 2.462 | | 4.489 |
| Society | | 1.762 | | | | 1.762 |
| Economy | | 0.882 | 3.020 | | 0.451 | 4.353 |
| Architecture | | 0.072 | | 1.891 | 0.946 | 2.908 |
| Government | 0.688 | | 1.596 | 0.404 | | 2.688 |
| Sum | 2.715 | 2.715 | 4.616 | 4.756 | 1.397 | 16.200 |

Not every local authority would make these difficult calculations; for those the following 'rules of thumb' can be very useful:

(a) Around half of the possible connections are valid. Ecological systems are self-regulated, and not all connections are used. In the city-example there are 25 possible connections (5 × 5 functional areas) and 12 proved to be useful in a resilient structure (Table 8).
(b) Each functional area has high impact connection(s), either one big or more lower impact projects in one connection which add up to a high impact. It is a more cost effective solution to concentrate on fewer projects with higher efficiency.

In the urban resilience planning process, designed in Fig. 1, there is a loop back to the project selection part until the impact matrix of the project approaches the optimal structure. The 'rules of thumb' provided above is a good guide for project planners. In reality, this is a dynamic process and the local government could follow up the actual developments of the city's life.

In the strategy of Pécs the planners could not undertake the new project selection phase, since they did not have appropriate connection with the operational level, where projects were generated.

### 7.2. Practical Considerations

The scenario discussed in Section 7.1 is the basic scenario, when there were no major efforts made to achieve the main goal of the city; and so the intentions, inherited in the projects "direct" the solution. However, it is possible to tailor the method to different circumstances.

1. There are cases, where there is already progress in certain areas (connections). In this case it is possible to anchor certain connections. If there are negative values in the cell after the first iteration, where positive developments have already taken place (see the first round at Table 7), then it needs to be replaced with a positive estimated impact value in order to preserve this connection during the calculations. An example: If there are significant green and blue surfaces in the city already, then the *Nature-Architecture* negative value of − 0.6688 can replaced by an estimated value, and calculations will be formed in accordance with this value.
2. "Double accounting" is also possible: if a city uses renewable energy, then it could equally be a *Nature-Society* and *Nature-Economy* connection. Either fix both values, or use the connection whichever is more significant
3. In cases where there are more anchored values the method is also operational, but it is possible, that more than half of the connections will be valid. Note that more resilient constructions exist, so cities can situate their "different ways of knowing" (Arora-Jonsson, 2016, p.98).
4. The optimization procedure can reach the optimal $\alpha$ value, although it is nearly impossible to reach the same optimum with concrete project impacts (see Fig.2). In this case the use of the $Fs$ value is

suggested, e.g. $Fs > 0.99$ is appropriate, since this indicator allows for a broader range for the optimum.

In the following section these features of the method will be used to formulate an “ideal” impact structure.

### 7.3. A Global Application

The *Introduction* section has already posed the necessity of the sustainability element of a resilient plan. Research, described in Section 1.1, has mainly aimed to achieve sustainability. In this section there will be an attempt to build these and other efforts into an “ideal” city plan, where the twelve of the most considerable efforts will be placed into a resilient structure. These developments will be built row by row.

First: *Nature – Society* connection. *Nature* can provide much for the mitigation of climate change with green and blue surfaces. Also, *Nature* helped Havana with permaculture (urban gardening) to survive the crisis in the 90s (Wright, 2009, p.235). *Nature* to *Economy* is the place, where e.g. the blue economy principles (Pauli, 2010) can be built in, which is an economy, based systematically on ecological systems (e.g. Las Gaviotas, Pauli, 2010, pp. 15–19). A number of blue economy cases can be used in *Architecture* (such as termite mounds' building design, Pauli, 2010, pp. 207–208). Efforts of society in recycling, water and energy savings are a *Society-Nature* connection. Living Labs are a user co-creation innovation/development approach, where people are in the centre[2] (*Society-Architect*). Social activists should promote the question of co-governance (Ackerman, 2004). Development of the local economy can provide jobs, and income for the inhabitants (smaller scale), or Prahalad (2006) describes cases where multinational companies can provide high level ‘win-win’ solutions to society (*Economy-Society*). However, the economy should build these activities into the normal operation of economic life (*Economy-Economy*). Paquot et al. (2012) collects several sustainable cases, made by *Architecture* to *Society*, such as involving homeless people into the building planning process (WinziRast, Paquot et al., 2012, p. 42). The resource and energy efficient building (e.g. LifeCycle Tower, Paquot et al., 2012, p. 45) refers to the realm of *Architect-Architect*. Government's task is the environmental protection, actions for mitigating climate change (*Government-Society*), and finally, social activists, who become members of local government, would be willing to allow or help co-governance (Ackerman, 2004) as a *Government-Society* connection. The result is depicted in Table 9.

The number of valid connections is twelve, as in the case of the automatic resilience construction. The process started from equal weights (from 2). This structure would probably need more transformational work from cities to implement it successfully.

In summary, this section showed that both local and global sustainability efforts could be organized into resilient structures.

## 8. Additional Thoughts and Limitations

Projects are the building blocks of the strategy, which are partly determined by the sub-goals and policy directives. However, the culture of the city, the local authority and the planners are also important. Culture in the resilience literature means “… the webs of meanings and significance that people weave about their lives” (Arora-Jonsson, 2016, p. 100). Resilience requires the integration of the different functional areas in order to cover the whole system examined. The pressure to rethink the activities of the different areas fosters the spread of resilience thinking, ecoculture and sustainability; therefore, the planning and implementation process will influence local culture. This process also promotes the development of the different sub-cultures (e.g. economic culture, social culture, ecoculture) of local society to move to a comprehensive approach.

[2] See e.g. http://www.openlivinglabs.eu/node/1429, downloaded at 10.07.2017

**Table 9**
Optimal structure, based on research cases.

| | Nature | Society | Econ. | Arch. | Gov. | Sum |
|---|---|---|---|---|---|---|
| Nature | | 0.683 | 2.25 | 1.310 | | 4.243 |
| Society | 1.615 | | | 0.874 | 4.583 | 7.072 |
| Economy | | 1.365 | 3.594 | | | 4.959 |
| Architecture | | 1.582 | | 2.64 | | 4.222 |
| Government | 3.693 | 1.361 | | | | 5.054 |
| Sum | 5.309 | 4.991 | 5.844 | 4.824 | 4.583 | 25.550 |

The known limitations of the methodology are the following:

- The correct application of the Delphi method is time-consuming, and should be partly repeated when new projects are generated;
- Finding suitable projects needs the planners to understand the methodology;
- It might be difficult to find the right version from the different resilient solutions which will be the most appropriate local solution;
- If planners do not want to use the ‘rule of thumb’ method, they need to run e.g. the *enaR* package (R-package), which needs expertise.

Future extensions:

- This methodology provides a tool for planning a resilient structure for city strategy, although the desirable scale of these impacts is a matter for further research.

If the local authority has the proper intention and funding to complete the strategy as it is framed in this paper, then the whole of city life and culture would move to a resilient, and sustainable direction. This modified culture will not only ease the reaction of citizens, governors, the leader of the local economies to respond to a crisis, but they will have a resilient city structure with more opportunities to react.

## 9. Conclusion

Resilience is becoming a buzzword in our society, regions and cities. This paper argues that in socio-ecological systems, resilience – by definition – does not necessarily mean sustainability. In the planning process of these systems, the sustainability element needs a special focus.

The notion of resilience is usually linked with a physical phenomenon, such as an ecological niche, or city infrastructure. This paper was conceived rather differently: it examines the structural resilience of a city strategy, based on the impacts which the elements of the functional strategies (projects for goals, sub-goals) have on other functional areas.

The strategy building process starts with setting the main goal of the city, which is – in the case of Pécs – building a sustainable city. Policy directives communicate this main goal. Functional areas were selected with goals and sub-goals, and projects were planned to fulfil the different sub-goals. Experts evaluated the impacts of these projects. Spreadsheet models helped in the project selection and an ENA model was elaborated for testing and creating a resilient urban strategy. In this way a resilient project portfolio was compiled. This strategy is not only resilient but sustainable as well, because of the nature of the involved projects. Global sustainability efforts were also organized into a resilient structure. Additionally, ‘rule of thumb’ statements were provided for those planners who lacked a strong mathematical background.

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## Appendix A. Within-project Synergy

The projects, drawn up at operational level, are usually complex and contain sub-projects to achieve the given purpose. The lack of sub-projects endangers the project as a whole. One example relates to an airport, which contains three sub-projects, but where, lacking one factor, the airport could not operate in accordance with the planned purpose. Table A.1 shows the situation where stand-alone projects, a *market-hall for local products* and an *airport project*, are featured. In the case of the latter, the physical construction of the airport has a value of − 40%, meaning that building a non-operational airport would simply be a waste of money. The other two elements (*b* and *c*) indicate that these factors are necessary to operate the airport, and have high values (140% all together) to balance the first factor's − 40% value.

Table A.1
Within-project synergy in respect of two projects.

| Compact city – balanced city structure | Involved (0/1) | Percentage | Synergy indicator |
|---|---|---|---|
| Local market-hall for local products | 1 | 100 | 1 |
| Airport | 1 | 30 | 0.59 |
| (a) Premises | 1 | − 40 | |
| (b) Feasibility study (positive) | 1 | 70 | |
| (c) Contract with airline | 0 | 70 | |

The synergy indicator measures how the project can achieve the original purpose if the project is carried out. This indicator could serve as a weight for the project in further calculations. In the case of the market-hall, this impact is 100%, as no other, supplementary subproject is needed to achieve the desired impact (in the case of Pécs, an old, operating market-hall would be replaced), whilst, in the second case – the airport – this percentage is only 30%, as there is no airline willing or able to operate regular flights here. However, the connection between the percentage and its effect is non-linear, and so a synergy indicator ($s_i^w$) is created:

$$f(p_i) = s_i^w = 1.135 - e^{\frac{-2p_i}{100}} \tag{A.1}$$

where *i* is the given project; $p_i$ is the percentage value of the project, and $s_i^w$ is the function of $p_i$. This indicator can be calculated for each project. This function can be individually tailored to a specific environment (even, the simple percentage value can be used), although the nonlinearity of the indicator is useful.

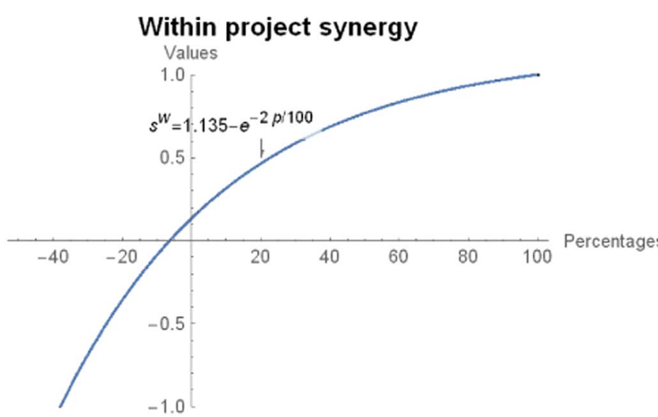


**Fig. A.1.** Within-project synergy indicator.

Fig. A.1 demonstrates the percentages (*x*-axes) and the corresponding synergy indicator (*y*-axes). Note that the percentage can be a negative value also. In this specific case the 30% means a 0.59 weight for the airport project.

The estimate of the within-project synergy indicator is contained within. This is the planners' task, but it also could be asked of the experts.

## Appendix B. Sub-goal Coverage Indicator

The projects initiated would probably never achieve the goals perfectly. In Table B.1 two projects achieve 80% of one of the economic sub-goals.

Table B.1
Estimate of the projects' participation on the sub-goals of the functional areas.

| | Involved (0/1) | Sub-goal |
|---|---|---|
| Project 1 | 1 | |
| Project 2 | 1 | 50 |
| Project 3 | 1 | |
| Project 16 | 0 | 30 |

| | | |
|---|---|---|
| Project 17 | 0 | |
| Total | | 80 |
| Involved | | 50 |

In this case, Projects 2 and 16 are relevant and they would achieve 80% cover for this sub-goal. However, Project 16 is not involved in the final project set, and so the real ratio is only 50%.

The estimate of this indicator is also kept within the realm of the planners, similarly to the within-project synergy estimate. This indicator has a very important role. Firstly, it highlights the fact that the projects involved cannot cover the sub-goals adequately, and, secondly, it assists the generation process of the new project, which might be needed after the resilience test (see Section 7). Thirdly, the difference between the total and involved values reveals that an insufficient number of projects were implemented.

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