Unveiling the complex connectivity of human needs in urban places. Towards a better understanding of the social dimension of sustainability.

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Abstract

We present a methodology based on complex networks and maximal information methods that, using data from surveys on urban perception at two spatial levels, reveals the connectivity between human needs. Questions, linked to needs by their satisfiers, are represented by nodes, and correlation between them by edges, weighted by the information strength of every pair of questions. Graph theory is applied to reveal the structure of the network. Our results show that different spatial levels present different and non-trivial patterns of need emergence. A simple numerical model suggests a dependency on the probability distribution of weights. This way of visualising the connectivity of human needs can be used to devise new strategies to cope with the complexity of urban-making processes.

Keywords:

Human needs; Information strength; Complex networks; Human scale development; Urban places; Sustainability.

1 Introduction

In recent years, sustainability science has incorporated many, usually complementary, frames of reference in order to facilitate the vision of sustainable futures (Kajikawa, 2008; Sumi, 2007). Since the Brundtland report (WCED, 1987), which broadened the definition of sustainability to encompass the entire range of human values (Ascher, 2007), this vision has included an evolving definition of the overall human quality of life as a function of both the level of human needs met and the extent to which individuals or groups are satisfied with this level (Costanza et al., 2007; Max-Neef, Elizalde, & Hopenhayn, 1991). Whereas human needs are constant, finite, few and classifiable, the way in which these needs are satisfied changes over time and between cultures. The satisfiers required to fulfil each need must come from the social contract. They must involve various types of capital (i.e. time, built, natural, social or human) and be based on a) the generation of growing levels of self-reliance, and (b) the construction of organic articulations of people with nature and cultural environments, of global processes with local activity, of the personal with the social, of planning with autonomy, and of civil society with the state (Max-Neef, 1992). During the history of human kind, this construction has been performed to increasing degree in urban places. The term *place* here is used to designate a setting that takes into account various combinations of social, cultural, communal, economic and ecological facets (Marsden, 2013). Urban places are thus complex expressions of the varied interactions between these interconnected and interrelated spheres.

Complementarily, sustainability science, not being a ''science'' by any usual definition[1], rather consisting of a plethora of ideas and perspectives (Rapport, 2006), has been conceptualised as an advanced form of complex systems analysis (Wiek, Ness, Schweizer-Ries, Brand, & Farioli, 2012). It is clear that, in order to build diagnostic and analytical capabilities as an applied science using scientific knowledge acquired in separate disciplines (Ostrom, 2007), it needs to incorporate and develop entirely departing research strategies and methodologies such as multi-level transition theories and socio-technical systems, questions of panarchy (i.e. resilience and vulnerability), theories of rural and regional development, and in particular, complexity science (Marsden & Farioli, 2015). In this sense, in recent years, most of the effort in complexity science has been devoted to developing a unified theory of urban living (Batty, 2012; Bettencourt & West, 2010). With 52% of people (78% in more developed regions) now living in cities (United Nations, 2014), sustainability science greatly needs to find a predictive framework where dynamics involved in the on-going expansion processes of urban areas can be included. The application of mathematics in social sciences is now essential for the study of society and groups as more and more human systems are complex and interconnected (Bonacich & Lu, 2012). In this regard, our understanding of urban places is being transformed by new approaches where cities are treated as complex adaptive systems—characterised by structures, processes, social and technological networks and interactions—that give rise to morphologies, which illustrate fractal patterns, self-similarity and scaling laws (Batty, 2005; Bettencourt, Lobo, Helbing, Kühnert, & West, 2007). However, results so far have been concentrated essentially in the descriptive-analytical or problem-focused domain, rather than in the transformational or solution-oriented mode (Wiek et al., 2012). Since most people's sense of well-being depends on the social and cultural system in which they are living (Sumi, 2007), any approach (coming from complexity science or not) that does not take into account, on an equitable basis, the human needs and the changing aspirations of a community is of very limited use (Kajikawa, 2008).

This paper aims at unveiling the complex expression of human needs in urban places to better understand the social dimension of sustainability. It addresses this particular dimension of social science theory from an empirically informed bottom-up perspective. Fundamental human needs (i.e. Subsistence, Protection, Affection, etc.) can be classified according to existential categories

[1] It is not yet a set of principles by which knowledge of sustainability may be systematically built.

(i.e. being, having, doing and interacting) in order to create multi-dimensional matrices that can be filled with examples of satisfiers for those needs. However, the manner in which a community builds its particular social framework based on preferential needs or existential categories has not yet been investigated in the research literature. This paper presents a methodology based on complexity science (complex networks and maximal information methods in particular) that, using data from public surveys on urban perception, unveils the complex connectivity between human needs. The questions related to how these needs are satisfied are represented by nodes, and the correlation between such questions is represented by edges, weighted by means of information strength (i.e. maximal information coefficient) for every pair of questions. Graph theory is then applied to reveal the structural properties of the weighted network, which acts now as a map of the connectivity of human needs. Finally, a discussion is made of how the results can be used to accommodate the particular heterogeneity and diversity of places and scales, and how this new way of visualising the emergence of satisfiers and human needs can be used to devise new strategies to cope with the complexity of urban-making processes.

2 Materials and methods

2.1 Study categories

To define the study categories applied in this analysis, the Human-Scale Development (H-SD) paradigm developed by Manfred Max-Neef et al. (1991), partially modified by Costanza et al. (2007), was adopted. Human needs indicate deprivations and, at the same time, individual and collective human potential. Needs are seen as finite, few and classifiable, changing only at a very slow pace along with the evolution of our kind. They can be satisfied according to many criteria. In this case, the axiological needs were used, with categories corresponding to Subsistence, Protection, Affection, Understanding, Participation, Leisure, Creation, Identity and Freedom. Protection was changed by Security, as per Costanza et al. (2007), and Subsistence was considered within Reproduction, the latter being understood as a part of the former. Spirituality has been also included as a study category, because of its importance in the assessment as a need (O'Brien, 2005; Van Dierendonck, 2011).

The fulfilment of all needs (or categories) is considered equally important. Any unsatisfied or inadequately satisfied human need reveals a form of human poverty, hindering happiness, and thus, having the capacity to develop potential pathologies (Cruz, Stahel, & Max-Neef, 2009). The satisfiers of these needs change over time and between cultures. There is no one-to-one correspondence between needs and satisfiers. A satisfier may contribute simultaneously to the satisfaction of different needs or, conversely, a need may require various satisfiers in order to be met. These relations are not fixed; they may vary according to time, place and circumstance (Max-Neef et al., 1991). Each economic, social and political system adopts different methods for the satisfaction of the same fundamental human needs. In every system, they are satisfied (or not satisfied) through the generation (or non-generation) of different types of satisfiers.

2.2 Surveys and study cases

For the purpose of this study, and to assess possible differences in spatial scales, two simple and accessible surveys were created, which could be completed both online and in person (Papachristou & Rosas-Casals, 2015). Their goal was to study the perceptions related to two different urban places within the same area (Barcelona, Spain): the neighbourhood of Vila de Gràcia (Gn) and Plaça de la Virreina square (Vs), respectively. Surveys were made available between May–June 2012 (Gn) and September–October 2014 (Vs). For the Gn case, the surveys could be completed online or in person, while for Vs, they could only be completed in person due to its reduced spatial scale. The total number of completed surveys was 174 and 51 for Gn and Vs, respectively.

Gn and Vs were essentially chosen for their cohesive urban and social fabric, providing high levels of participation and public engagement. Gn is characterised by an irregular urban grid with narrow streets and 16 public squares, many of which are considered to be emblematic[2]. The neighbourhood occupies the third position in terms of population in the city of Barcelona, with 50,448 inhabitants (Ajuntament de Barcelona, 2014) out of 120,273 living in the Gràcia district, distributed within 1.3 km^2 and with a population density of 38,806/km^2. The neighbourhood is characterised for preserving its 'village' identity with (still) strong social cohesion. The use of public spaces in this neighbourhood is very intense and subject to high demand, often creating the need for balance between the well-being of the residents and the activities in the public space. One of its most emblematic public spaces is Plaça de la Virreina. Vs was built in 1878 (when Gràcia was still a village on the outskirts of Barcelona) and continues to be one of the places within the area that gives the neighbourhood its "sense of village"[3]. This impression is created by the parish church of Sant Joan and a set of low-rise houses located to the right of the square, originally inhabited by workers from Vila de Gràcia's once very important textile industry.

2.3 Mapping needs onto questions

As suggested in Papachristou and Rosas-Casals (2015), to classify the survey questions into the ten fundamental human needs (or study categories), a study group of experts was selected, made up of researchers of the Sustainability Measurement and Modelling Lab[4] (SUMMLab) and the University Research Institute for Sustainability Science[5] (IS.UPC), both at the Universitat Politècnica de Catalunya – Barcelona Tech. The matching of the questions to one or more needs was treated as a subjective choice related to individual understanding and interpretation. The questions (and groups of questions) associated to satisfiers before the group of experts weighted them to needs can be found as Supplementary Material. The selected study group was first asked to review the questionnaires to detect any missing aspects, and then asked to match the given questions to the needs (Table 1). The first task was undertaken as a group, while the second task was performed individually, bearing in mind that a question could be related to

[2] http://lameva.barcelona.cat/gracia/ca/home/el-barri-de-la-vila-de-gracia
[3] http://graciapedia.gracianet.cat
[4] http://summlab.upc.edu/en
[5] https://is.upc.edu/?set_language=en

more than one need (i.e. a question such as "How satisfied are you with your health" can be matched with Subsistence, Security, Freedom and/or Spirituality).

Table 1: Questions are classified into needs by following and averaging a simple binary decision from experts. Here, need A is assumed to be defined by questions $1, 2, \dots, m$ and by experts $a, b, \dots, n$. The importance of question m in defining need A is the average of experts who acknowledge this importance.

Need A					
Question	**Expert a**	**Expert b**		**Expert n**	**Average**
1	1	1	…	1	3 / 3
2	1	1		0	2 / 3
			…		
m	1	0		i	$\frac{\sum i=1}{n}$

In order to (a) detect the relevance of each question in defining each need, and (b) balance the amount of questions per need so every need is defined by a similar number of questions, questions per need were selected in decreasing average order. When the average punctuation for a question was equivalent for more than one need, a sequential criterion was used, based firstly on equal number of questions per need, and secondly on a random selection of pertinence. In order to detect any possible bias in the results when introducing this randomising step, the methodology explained below (Section 2.4) was reproduced several times. After having reproduced this part of the methodology with different sets of randomised values, it was shown that the results were not affected.

2.4 Overall connectivity of needs

To help us in explaining both individual answers and aggregate results better, a measure of dependence for two-variable relationships termed maximal information coefficient (MIC) was used (Reshef et al., 2011). MIC allows many-dimensional datasets to be explored, assuming generality (i.e. it captures a wide range of associations, not limited to specific functions such as linear, exponential, etc.) and equitability (i.e. it gives similar scores to equally noisy relationships of different types).

MIC values for independently taken pairs of variables cannot give a true account of the aggregate outcome of the answers. The particular relation between two questions (or their corresponding needs) is not of interest in this study, rather the overall connectivity map between questions and how this map emerges is relevant. To provide an intuitive and efficient interpretation of how the different variables in a dataset are related to each other, a network-type visualisation of the datasets was obtained. The questions in the dataset were represented by nodes, while the relationships between questions were represented by edges, weighted according to the MIC strength of each pair of variables.

Finally, the weighted degree of each node was obtained as a proxy of its significance and as a function of its MIC values with the rest of questions. In network theory, the degree of a node is simply the number of connections or edges that the node has to other nodes. Weighted degree has generally been extended to the sum of weights when analysing weighted networks (Barrat, Barthélemy, Pastor-Satorras, & Vespignani, 2004; Newman, 2001; Opsahl, Agneessens, & Skvoretz, 2010), and it is labelled *node strength*. This measure is formalised as follows:

$$s_i = \sum_j^N w_{ij} \qquad (1)$$

where w is the weighted adjacency matrix, in which w_{ij} is greater than 0 if the node i is connected to node j and the value represents the weight of the tie, in our case, the maximal information coefficient (MIC). Once a network is thus created, graph theory can be applied to reveal other structural properties based on network centrality measures (Newman, 2010). Here, strength (i.e. weighted degree) cumulated probability distribution $P_>(s_i)$ has primarily been used, measuring the percentage of nodes with strength s_i or higher. A remarkable attribute of cumulated distributions, compared to histograms and other binning procedures, is that no statistical information is lost. In many ways, it is a much more useful and convenient method for plotting the data (Newman, 2005). In order to be able to compare both networks, s_i has been normalised using the highest degree s_i^{max} for each network as the normalising constant:

$$\widehat{s_i} = \frac{s_i}{s_i^{max}} \qquad (2)$$

3 Results

The results from Table 1 are shown in Figure 1. This representation shows our first classification of the survey questions into fundamental human needs by the experts. Peripheral nodes represent questions and groups of questions (used when one question in the survey was subdivided in others and to prevent the figure from being overloaded). Central nodes represent needs. Node size is proportional to the number of connections a need or question has. Edge width is proportional to the importance of that question in defining that need (i.e. the average of experts who acknowledge its importance, value taken from column *Average* in Table 1). Colours have been used to highlight the modularity of the initial network. Modularity is a measure of the network structure, designed to measure the strength of division of a network into modules (also called groups, clusters or communities). It is defined as the fraction of the edges that fall within the given groups, minus the expected such fraction should edges be distributed at random (Newman, 2002). It can be seen that, although there are ten needs or study categories, initially there were only five identified clusters, with the largest one including Creativity, Leisure, Spirituality and Freedom, followed by the second largest including Security and Subsistence, the third with Participation and Identity, and the fourth and fifth with Affection and Understanding, respectively. This pattern indicates those categories where it is more common to allocate the different questions. It can be observed that Creativity, Leisure, Freedom and Spirituality (represented by a dark blue colour in Figure 1) share many common nodes, and as a result, belong to the same cluster. The same happens with Identity and Participation (shown in green) and Subsistence and Security (shown in light blue).

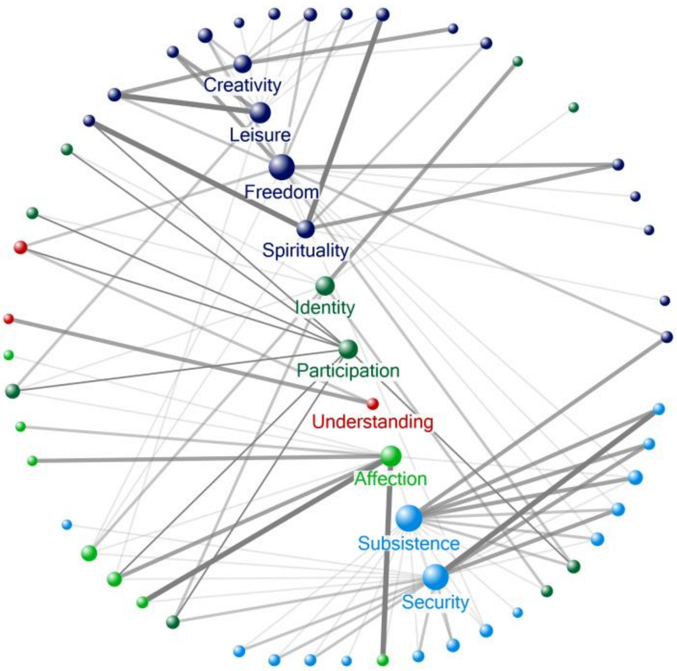

Figure 1: Initial connectivity of questions (perimeter nodes) and needs (central nodes). Node size is proportional to the number of connections (i.e. degree) that a need or question has. Edge width is proportional to the importance of that question in defining that need (i.e. the average of experts who acknowledge its importance). Colours have been used to emphasize modularity (see text). Graph figure created with NodeXL (http://nodexl.codeplex.com).

Although many questions (or group of questions) were originally related to more than one need, a subsequent processing of sequential selection was performed, where questions were selected in decreasing average order per need (see previous section). This balanced the number of questions per need, so every need was defined by a similar number q of questions on average; in this case $\bar{q} = 12$ and standard deviation $SD_{\bar{q}} = 2.5$.

As previously commented, here strength (i.e. weighted degree) cumulated probability distribution $P_{>}(s_i)$ was used as the fundamental measure to reveal human need connectivity. Since $P_{>}(s_i)$ measures the percentage of nodes in the network with strength equal to or greater than s_i and, at the same time, these nodes have been divided into needs, $P_{>}(s_i)$ offers the possibility to observe the evolution in the emergence of each need in accordance with the appearance of each question in the network, ordered from highest to lowest strength. This process can be presented qualitatively (Figure 2) and quantitatively (Figure 3). Figure 2 shows two particular screenshots corresponding to the emergence of the graph for Gn at two particular stages. When 15% of the nodes with the highest strength are shown (left), Affection and Security appear as the two most prominent needs in terms of correlations between questions. When strength is decreased in order to make 70% of the nodes present (right), Affection and Security have fully appeared, while other needs still are to be defined (i.e. Participation). At this stage, the graph is still far from being fully connected and all non-present nodes have strengths lower than 0.35. Here, questions have been spatially grouped and coloured according to H-SD categories.

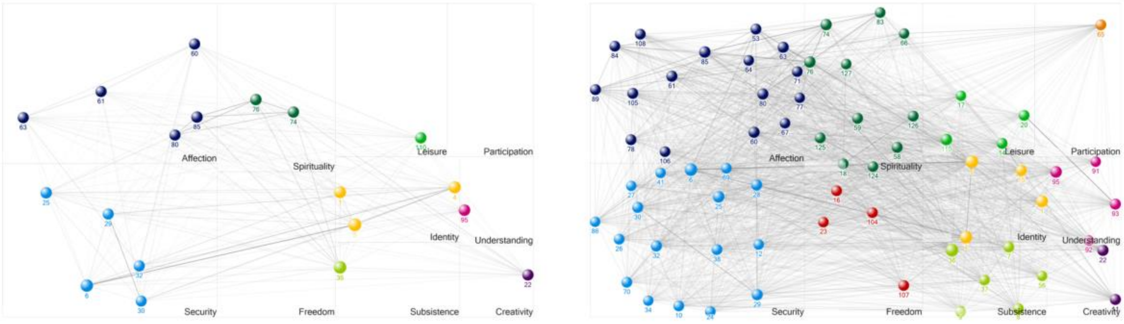

Figure 2: Appearance of needs (different colours) using strength as a filter for the Vila de Gràcia network. Graph snapshots when 15% (left) and 70% (right) of the nodes with the highest strength are shown, respectively. Graph figures created with NodeXL (http://nodexl.codeplex.com).

The results for the normalised strength cumulated probability distribution for both networks, Gn and Vs, are shown in Figure 3. $P_{>}(s_i)$ exhibits a bimodal distribution for both networks, with two similar sigmoid behaviours after and before strength value $\widehat{s_i} = 0.35$ for Gn, and $\widehat{s_i} = 0.25$ for Vs. Figure 3(a) shows its deviation from the corresponding cumulated probability distribution for a random graph (i.e. a graph with Gaussian degree distribution) with the same average node strength and number of nodes. This deviation (shown with dashed lines) is more substantial in the case of Vila de Gràcia. Figure 3(b) shows $P_{>}(s_i)$ for the same nodes, but this time, it is grouped by need. Here, the particular characteristics of every need can be observed and how its importance (in terms of more connected nodes or questions) emerges gradually from the entire connected network and at some particular transitional zones, numbered from (I) to (III). The features that can be observed are the following:

- One striking difference between both distributions is shown in Figure 3 (a). Gn presents more homogeneous normalised strength distribution than Vs. This can be clearly observed by the number of nodes existing in the range $0.5 < \widehat{s_i} < 1.0$ for both networks: $P_{>}^{Gn}(s_i \geq 0.5) = 0.4$ whereas $P_{>}^{Vs}(s_i \geq 0.5) = 0.02$. Although qualitatively similar, this characteristic keeps both distributions segregated and quantitatively distinct, as it will be commented later.
- For both networks, nodes related with Identity appear first, indicating their highest normalised strength (i.e. $\widehat{s_i} = 1.0$). In the case of the Gn network, nodes connected with Security and Understanding appear as early as for $\widehat{s_i} > 0.89$ and $\widehat{s_i} > 0.67$, respectively.
- Zone (I). For $\widehat{s_i} = 0.55$, a first sudden transition for Gn is observed when nodes related with Affection, Creativity, Freedom, Leisure, Participation and Spirituality categories mostly appear. This implies the presence of 30% of the nodes in Gn, while barely 2% of the nodes in Vs are present for this same value of $\widehat{s_i}$. Nodes related with Subsistence have already completely appeared in the distribution from normalised strength $\widehat{s_i} = 0.45$.
- Zone (II). There is not a second transition until $\widehat{s_i} = 0.34$, this time, for the Vs network. At this point, nodes related to all categories have already appeared, although some of them only with a reduced presence (i.e. Freedom, Leisure and Participation). Here, 70%

of the nodes are already present in the Gn connected component of the graph, while only 35% of their counterparts in Vs have appeared.

- Zone (III). Finally, for $\hat{s_i} < 0.3$, the remaining nodes appear in a process of slow convergence between the two networks shown in Figure 3(a). For the Vs case, however, some sudden transitions occur for the Creativity, Freedom, Leisure and Participation categories. Curiously enough, the two only needs in Vn that reach a final presence in the network with percentages similar to those of Gn are Affection and Security.

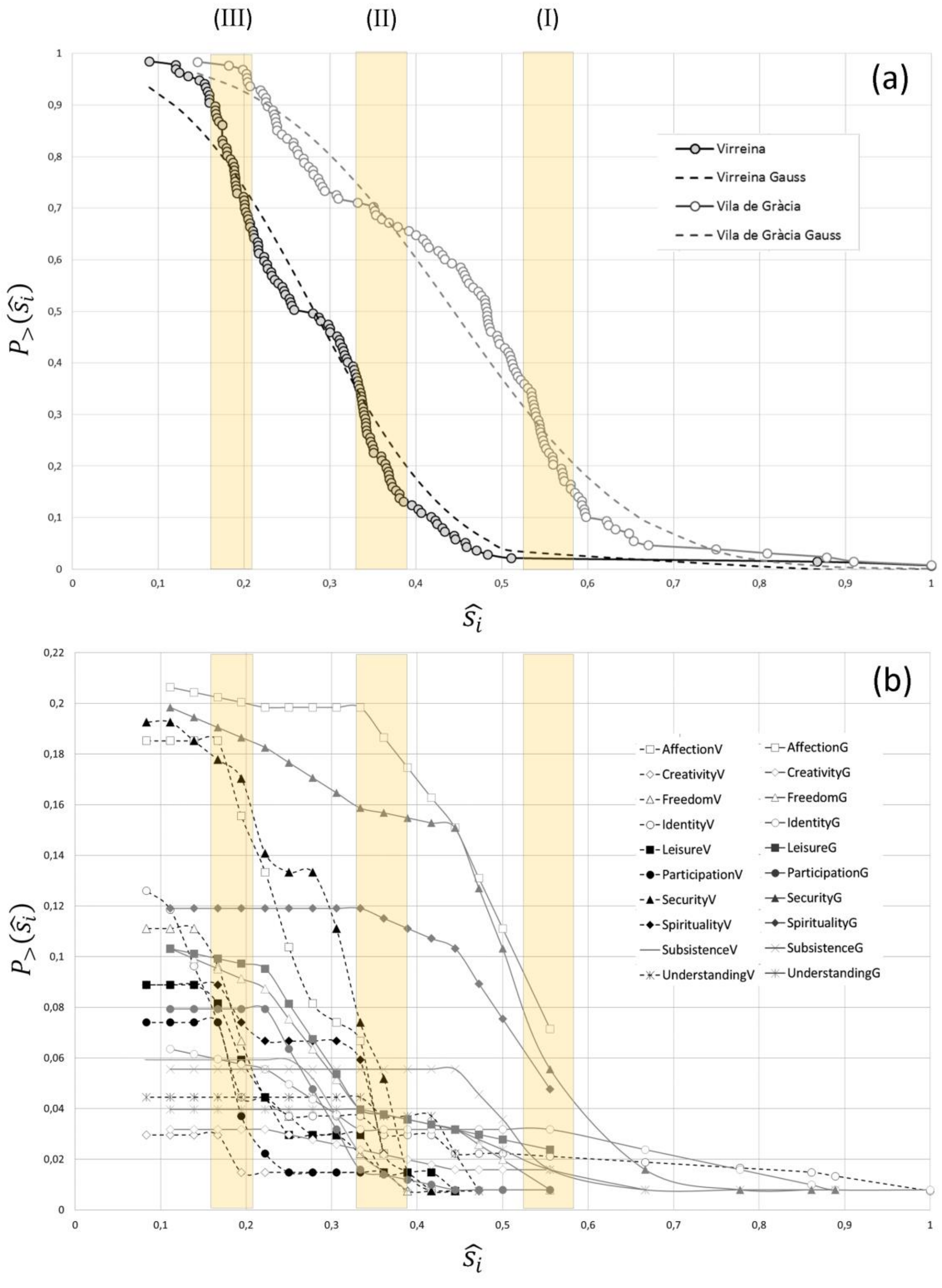

Figure 3: Figure 3: Strength (i.e. weighted degree) cumulated probability distribution and the emergence of the dataset network. (a) Degree cumulated probability distributions for Plaça de la Virreina square (Vs) and Vila de Gràcia neighbourhood (Gn), compared to a normal distribution with the same average weighted degree and standard error (dashed line). (b) Segregated by needs. (V stands for Plaça de la Virreina; G stands for Vila de Gràcia). Grey colour has been used to reduce overlapping. Coloured strips (I), (II) and (III) are related with transitional zones (see text).

4 Discussion

The structure of the connectivity of human needs presented here must be understood as a global emergent trait from a particular spatial and temporal sample, and hence, cannot be taken out of this precise context. It would also be inappropriate to examine the importance of the different questions by means of their individual connectivity, i.e. which particular question is connected to which other particular question. Although we acknowledge the necessity for an axiomatic approach to the concept of complexity and its many applications in the form of network in general, and social networks in particular (Butts, 2000), the analysis introduced in this paper aims at presenting a proxy of how a community builds its particular social contract based on preferential needs. Other kind of conclusions that may be derived from it must be taken with due care for at least three reasons. Firstly, null models for comparative purposes cannot be formulated in the case of such specific graph construction processes. Secondly, the strength probability used as a question classifier is a statistical index derived from maximal information coefficients between pairs of questions. Thus, in a group of n questions, the importance of a question depends on its (co-)relation with the remaining $(n-1)$ questions. Lastly, the classification of questions into human needs comes, in this case, from a pool of people who, despite being experts in their fields, share a particular and time- and space-limited vision and definition of H-SD. That being said, what is observed here is the appearance of the complex expression of human needs in one particular urban place and time, and on two scales: neighbourhood (Gn) and square (Vs). From an overall point of view, some important features can be highlighted and commented in terms of $\widehat{s_i}$ and $P_>(s_i)$. First of all, and on both scales, Identity appears as the most prominent need. Under H-SD's existential categories (i.e. being, having, doing and interacting), Identity implies belonging (to a place), language, habits, traditions and values. It is thus a fundamental need in the definition of a reference group and the recognition of one's self in the social sphere. This is the only common trait shared by both networks. At the local scale (Gn), Security appears in second place, a need related with solidarity, family, rights and job. Once again, it is a fundamental need in the definition of vital and social domains. On the other hand, the striking difference between Gn and Vs networks is the $\widehat{s_i}$ value at which the rest of the needs begin to appear: above and below $\widehat{s_i} = 0.5$, respectively. This difference comes essentially from a fundamental change in the strength homogeneity. Gn presents a much more evenly spread distribution in terms of $\widehat{s_i}$ than Vs, where questions for all needs appear suddenly, in a much more concentrated manner. In Gn, normalised strength spans in a wider range than in Vs, with nodes occupying the whole spectrum of $\widehat{s_i}$ values. From a structural point of view, the strength of the different questions related to Gn and, consequently, the gradual appearance of needs are ruled by some particular questions whose bonds are slightly more developed and shared than in Vs. Affection (related with self-esteem, friendship and family), Creativity, Leisure and Participation (related with imagination, humour and curiosity), and Spirituality (related with beliefs and personal growth) appear as needs defining connectivity at this level of scale. One possible explanation of this feature might come from the local (i.e. neighbourhood) sampling scale, where much more overarching visions and perspectives are expected than at a sub-local (i.e. square) level. Following this rationale, the sub-local level implies a much more limited vision, with connectivity less clearly dominated by particular needs.

Although we assume the impossibility of formulating a generative null model for comparative purposes in this case, a very simple numerical model can help us understanding the influence of the distribution of weights in the observed probability distributions of Figure 3. Let assume a fully connected graph $G(m,n)$ with n nodes and $m = n(n-1)/2$ edges, as it is the case in our original network, where every node i is connected to every other node j. Our objective is to detect qualitative differences in cumulated probability distributions of strengths coming from different probability density functions of weights $f(W_{i,j})$. To do so, the following algorithm is used:

1. A number $m_{W_{i,j}} = n(n-1)/2$ of weights is generated from two different probability density functions: exponential ($W_{i,j} \leftarrow q(x) \sim e^{-x}$) and power law ($W_{i,j} \leftarrow p(x) \sim x^{-\beta}$). We have considered these two functions as they imply the statistical signature of two extreme phenomena commonly considered in the literature (Gros, 2015; Mitchell, 2009): that of randomness and that of some sort of complexity, respectively. In the particular case of networks, a fat-tailed probability distribution signature (i.e., power law) in terms of degree indicates a hub-dominated topology, where the probability of finding a node with high degree is significantly higher than in a homogenous graph case (Newman, 2010). This fact implies non-trivial underlying mechanisms for the generative processes of a network's evolution and growth.
2. We use α as a threshold in the range $0 < \alpha \leq 1$ to parameterize the steps of assigning values to the weighted adjacency matrix of our particular synthetic network, with weights $W_{i,j}$ randomly drawn from $p(x)$ if $k \leq \alpha$ and from $q(x)$ otherwise, where k is a random number in the range $0 < k \leq 1$, generated at every step. For $\alpha = 0$, the model fills a weighted adjacency matrix with weights purely coming from an exponential probability density functions of weights, whereas for $\alpha = 1$, the model fills a weighted adjacency matrix with weights solely coming from a power law one.
3. For different values of α, the corresponding normalised strengths are calculated for every node (Eq. 2) to finally obtain the corresponding cumulated strength probability distribution $P_{>}(s_i)$ for each α.

Figure 4 shows averaged values (with standard errors shown as whiskers) for $P_{>}(s_i)$ and for 100 realizations over a network with $n = 100$ nodes using some values of α. Although we observe differences as α moves from 0 to 1, each cumulated strength probability distribution qualitatively follows a cumulated normal distribution (p-value < 0.001 for all of them, results not shown in the text). As a first immediate outcome, our model shows how adjacency matrices filled with weights coming from different probability density functions give rise to qualitatively similar cumulated strength probability distributions. We use the coefficient of variation $c_v = \sigma/\mu$, where σ is the standard deviation and μ is the mean, to quantitatively distinguish the results of our model (Table 2). The coefficient of variation changes from $c_v = 0.53 \pm 0.07$ for the exponential case (i.e. $\alpha = 0.0$) to $c_v = 0.12 \pm 0.01$ for the power law case (i.e. $\alpha = 1.0$), indicating how an increasing probability of having nodes with larger strengths tends to diminish c_v.

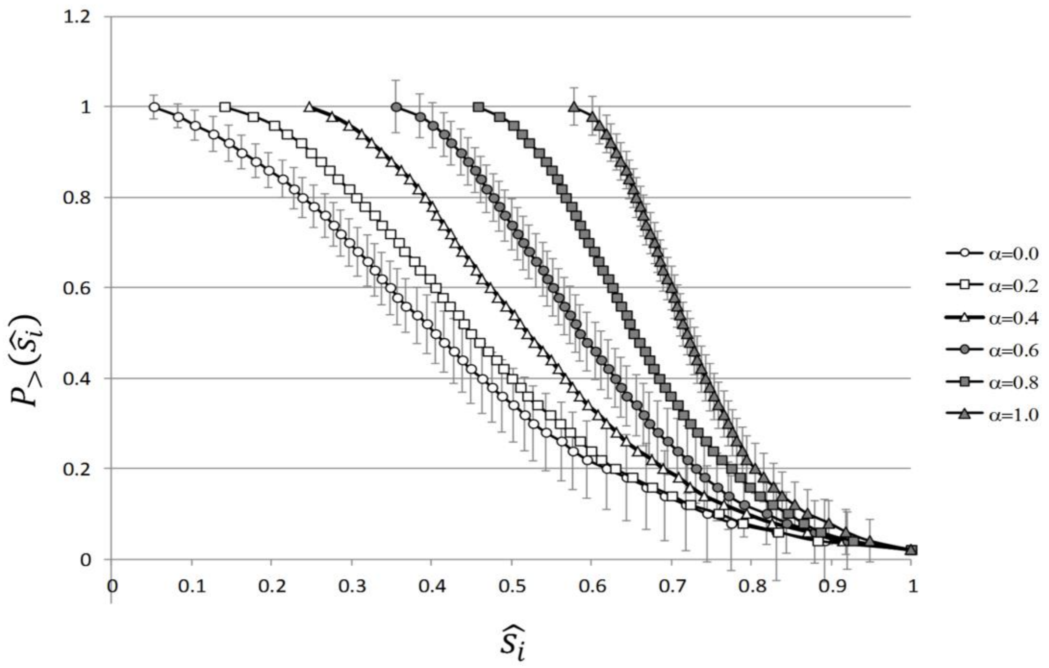

Figure 4: Synthetic strength probability distributions created from weights randomly drawn from exponential (grey) and power law (white) distributions. Standard errors shown as whiskers.

Table 2 also shows real c_v values for Plaça de la Virreina (Vs) and Vila de Gràcia (Gn), obtained from a fitting of a cumulated normal distribution (Figure 3). Although both cases differ slightly, our model sets Vs closer to the exponential case than Gn, thus shedding some light to those features previously commented. From a structural point of view, the strength of the different questions related to Gn and the gradual appearance of needs are ruled by hub-questions whose bonds (i.e. edges) are slightly stronger than in Vs. Following this rationale, the sub-local level implies a much more limited vision, with connectivity less clearly dominated by particular needs and ruled by exponential decay.

Finally, the remarkable similarity between both networks is illustrated by the ultimate $P_>(s_i)$ values reached by Affection and Security ($0.18 < P_>(s_i) < 0.22$), compared to those attained by the remaining needs ($P_>(s_i) < 0.13$). When all questions are considered, the probability of having nodes connected and classified under the needs Affection and Security is similar, suggesting more profound implications on their universality and social importance. One difference, though, is the rates at which these similar values of $P_>(s_i)$ are attained; much more abruptly for Vs than for Gn. Thus, Vs withstands a much more abrupt transition than its counterpart Gn for these two same needs. One unexpected consequence of this fact comes from the difference in strength distribution between Vs and Gn, as previously commented. If the probability of having nodes classified under the needs Affection and Security is somehow ubiquitous in both networks, a network of needs with less structural strength and exponentially decaying connectivity (i.e. Vs) will necessarily generate this connectivity much more suddenly than a more hub-dominated one (i.e. Gn).

Table 2: Results for the coefficient of variation of the mean values of the model and parameter α running from $\alpha = 0.0$ (exponential weight distribution) to $\alpha = 1.0$ (power law weight distribution), compared to our real study cases Plaça de la Virreina square (Vs) and Vila de Gràcia neighbourhood (Gn).

$\boldsymbol{\alpha}$	$\boldsymbol{c_v}$
0.0	0.53 ± 0.06
0.2	0.41 ± 0.05
0.4	0.33 ± 0.05
0.6	0.24 ± 0.03
0.8	0.18 ± 0.01
1.0	0.12 ± 0.01
Square (Vs)	0.42
Neighbourhood (Gn)	0.38

Considering the H-SD paradigm and moving into the social sphere of sustainability science, visualising human need emergence in this manner can be useful in devising new strategies to cope with the complexity of place-making process in general and urban-making ones in particular. The main assumption is that the presence of all needs (or categories) is equally important to avoid any form of human poverty. In this case, Identity dominates the global need connectivity on both scales, which is somehow an expected trend considering the idiosyncratic neighbourhood of Gràcia with a close-knitted social fabric that allows high levels of public engagement. While Affection and Security are the most connected needs on both scales, different probabilities of occurrence are observed for questions belonging to some particular human needs and on different scales. These probabilities are a function of how the satisfiers are perceived. A dissimilar probability of occurrence implies a different presence of satisfiers for the same needs. From these results, it is possible to devise more operational ways to balance the presence of those less-connected needs and to promote integration policies in this sense. For example, taking advantage of the well-defined (and also more difficult to alter) Identity and Security needs to advocate for designing and encouraging participatory thinking on new spaces for expression, workshops (i.e. Creativity), and meditation (i.e., Spirituality) within urban boundaries; or adopting Affection (a need with a high percentage of occurrence according to the probability distributions on both scales) and its existential categories (related with respect, generosity, family and relationships with nature) as a driving force for social and cultural change that may also lead to rewarding interactions in environments such as schools, universities, communities (i.e. Participation).

With a more defined vision on how needs are structured, the notion of place can be better conceptualised from a more embedded point of view, in order to meet the 'grand challenges' of sustainable adaptations and transitions (Marsden, 2013). In order to accommodate the particular heterogeneity and diversity of places and scales, the values and preferences that support future and converging visions of a place must be determined. This calls for value-laden stances of future generations to be included in visioning processes. It should start from an educational level: an egalitarian and integrative view of needs from an inclusive foundation. This can lead to a sense of caring (for people, environment, the future, etc.) and would overcome generic institutional barriers in implementing transition strategies.

Introducing a spatial and temporal perspective to this analysis is also fundamental. An important issue would be to reproduce this kind of analysis in other temporal and spatial lines, since temporal perspective raises public awareness of inter-generational phenomena (i.e. trade-off between short-term gains and long-term concerns) and spatial perspective brings an emphasis to intra-generational equity (Kajikawa, 2008; Martens, 2006).

5 Conclusions

The motivation to developing this comparative analysis on two spatial levels is to shed light on how needs are perceived (i.e. connected) on different scales, to suggest possible reasons for similarities and differences, and to propose, rather than postulate, how it can be used to answer some research questions in social science in general, and also related with that part of sustainability science more linked to social issues in particular. Although it is acknowledged that sustainability science is still characterised by the quest of how to move from complex-system thinking to transformational change, there are techniques coming from other fertile ideas that can be transversally transferred. Here a methodology based on complex networks and maximal information methods has been used to reveal the appearance and importance of the various human needs in the urban context. The consequences of this analysis can be used in implementing transformational projects in places. It presents an approach to define the function and aspect of sustainable human-environment systems (i.e. visions or desirable future states) and also introduces a tentative, yet viable, way to transition urban systems from their current state to a more sustainable one. The aim is to incorporate emerging models and conceptualisations on collective dynamic interactions to integrate social development and sustainability. The final objective is to reveal ways to improve social capacity to guide interactions between nature and society towards more sustainable trajectories.

6 References

Ajuntament de Barcelona. (2014). Departament d'Estadística. Retrieved October 15, 2015, from http://www.bcn.cat/estadistica/angles/index.htm

Ascher, W. (2007). Policy sciences contributions to analysis to promote sustainability. *Sustainability Science*, *2*(2), 141–149. doi:10.1007/s11625-007-0031-z

Barrat, A., Barthélemy, M., Pastor-Satorras, R., & Vespignani, A. (2004). The architecture of complex weighted networks. *Proceedings of the National Academy of Sciences of the United States of America*, *101*(11), 3747–52. doi:10.1073/pnas.0400087101

Batty, M. (2005). *Cities and complexity : understanding cities with cellular automata, agent-based models, and fractals*. Cambridge, Mass.: MIT Press.

Batty, M. (2012). Building a science of cities. *Cities*, *29*, S9–S16. doi:10.1016/j.cities.2011.11.008

Bettencourt, L. M. A., Lobo, J., Helbing, D., Kühnert, C., & West, G. B. (2007). Growth, innovation, scaling, and the pace of life in cities. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(17), 7301–6. doi:10.1073/pnas.0610172104

Bettencourt, L. M. A., & West, G. B. (2010). A unified theory of urban living. *Nature*, *467*(7318), 912–3. doi:10.1038/467912a

Bonacich, P., & Lu, P. (2012). *Introduction to Mathematical Sociology*. Princeton & Oxford: Princeton University Press.

Brandes, U. (2001). A faster algorithm for betweenness centrality. *The Journal of Mathematical Sociology*, *25*(2), 163–177. doi:10.1080/0022250X.2001.9990249

Butts, C. T. (2000). An axiomatic approach to network complexity. *The Journal of Mathematical Sociology*, *24*(4), 273–301. doi:10.1080/0022250X.2000.9990239

Costanza, R., Fisher, B., Ali, S., Beer, C., Bond, L., Boumans, R., … Snapp, R. (2007). Quality of life: An approach integrating opportunities, human needs, and subjective well-being. *Ecological Economics*, *61*(2-3), 267–276. doi:10.1016/j.ecolecon.2006.02.023

Cruz, I., Stahel, A. W., & Max-Neef, M. A. (2009). Towards a systemic development approach : Building on the Human-Scale Development paradigm. *Ecological Economics*, *68*(7), 2021–2030. doi:10.1016/j.ecolecon.2009.02.004

Gros, C. (2015). *Complex and Adaptive Dynamical Systems*. Cham: Springer International Publishing. doi:10.1007/978-3-319-16265-2

Kajikawa, Y. (2008). Research core and framework of sustainability science. *Sustainability Science*, *3*(2), 215–239. doi:10.1007/s11625-008-0053-1

Marsden, T. (2013). Sustainable place-making for sustainability science: the contested case of agri-food and urban–rural relations. *Sustainability Science*, *8*(2), 213–226. doi:10.1007/s11625-012-0186-0

Marsden, T., & Farioli, F. (2015). Natural powers: from the bio-economy to the eco-economy and sustainable place-making. *Sustainability Science*, *10*(2), 331–344. doi:10.1007/s11625-014-0287-z

Martens, P. (2006). Sustainability: science or fiction? *Sustainability: Science, Practice, & Policy*, *2*(1).

Max-Neef, M. A. (1992). Development and human needs. In M. A. Max-Neef & P. Ekins (Eds.), *Real life Economics: Understanding Wealth Creation* (pp. 197–213). London: Routledge.

Max-Neef, M. A., Elizalde, A., & Hopenhayn, M. (1991). *Human Scale Development. Conception, application and further reflections*. *Development Dialogue*. New York & London: The Apex Press.

Mitchell, M. (2009). *Complexity: A Guided Tour*. New York: Oxford University Press.

Newman, M. E. J. (2001). Scientific collaboration networks (II). Shortest paths, weighted networks, and centrality. *Phys. Rev. E*, *64*(016131).

Newman, M. E. J. (2002). Modularity and community structures in networks. *Proc. Natl. Acad. Sci*, *103*(23), 8577–8582.

Newman, M. E. J. (2005). Pareto laws, Pareto distributions and Zipf's law. *Contemporary Physics*, *46*(5), 323–351; 323.

Newman, M. E. J. (2010). *Networks: An introduction*. Oxford: Oxford University Press.

O'Brien, C. (2005). Planning for Sustainable Happiness: Harmonizing Our Internal and External Landscapes. In *Rethinking Development: 2nd International Conference on Gross National Happiness* (pp. 1–22). Antigonish, Nova Scotia, Canada.

Opsahl, T., Agneessens, F., & Skvoretz, J. (2010). Node centrality in weighted networks: Generalizing degree and shortest paths. *Social Networks*, *32*, 245–251.

Ostrom, E. (2007). A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(39), 15181–7. doi:10.1073/pnas.0702288104

Papachristou, I. A., & Rosas-Casals, M. (2015). An integrative methodology for the quality of life measurement in urban places based on the accomplishment of human needs. In *UN-Habitat Future of Places III Conference*. Stockholm.

Rapport, D. J. (2006). Sustainability science: an ecohealth perspective. *Sustainability Science*, *2*(1), 77–84. doi:10.1007/s11625-006-0016-3

Reshef, D. N., Reshef, Y. a, Finucane, H. K., Grossman, S. R., McVean, G., Turnbaugh, P. J., … Sabeti, P. C. (2011). Detecting novel associations in large data sets. *Science (New York, N.Y.)*, *334*(6062), 1518–24. doi:10.1126/science.1205438

Sumi, A. (2007). On several issues regarding efforts toward a sustainable society. *Sustainability Science*, *2*(1), 67–76. doi:10.1007/s11625-006-0021-6

United Nations. (2014). *World Urbanization Prospects The 2014 Revision Highlights*. New York.

Van Dierendonck, D. (2011). Spirituality as an Essential Determinant for the Good Life, its Importance Relative to Self-Determinant Psychological Needs. *Journal of Happiness Studies*, *13*(4), 685–700. doi:10.1007/s10902-011-9286-2

WCED. (1987). *Our Common Future*. Oxford University Press, USA.

Wiek, A., Ness, B., Schweizer-Ries, P., Brand, F. S., & Farioli, F. (2012). From complex systems analysis to transformational change: a comparative appraisal of sustainability science projects. *Sustainability Science*, *7*(S1), 5–24. doi:10.1007/s11625-011-0148-y