CITIES AND QUALITY OF LIFE. QUANTITATIVE MODELLING OF THE EMERGENCE OF THE HAPPINESS FIELD IN URBAN STUDIES

Ioanna Anna Papachristou [1,*] and Marti Rosas-Casals [1,2]

[1] Sustainability Measurement and Modeling Lab., Universitat Politècnica de Catalunya – Barcelona Tech, ESEIAAT – Campus Terrassa, Colom 1, 08222, Barcelona (Spain).

[2] ICREA - Complex Systems Lab., Universitat Pompeu Fabra (GRIB), Dr. Aiguader 80, 08003 Barcelona (Spain).

* Corresponding author: ioannapapachr@gmail.com, phone: +34937398369, fax: +34937398225

Abstract

Where we live affects all aspects of our life and thus our happiness. In recent years, and now for more than half of the population of the Earth, our place of residence or activity has been increasingly transformed into an urban one. However, while the impact of happiness studies has grown in importance during the last twenty years, we note that concepts like subjective well-being or happiness itself find it difficult to penetrate the planning and design of cities and truly affect the field of urban studies. In this paper we map the temporal evolution of the fields of happiness and urban studies into dynamic networks obtained by paper keywords co-word analysis. In order to reproduce the changes in its topology, a one-parameter spatial network model is presented. The results suggest an explanation for the level of penetration of these two fields in particular, but they also explain how different related academic or scientific fields evolve and pervade each other as a function of "conceptual distances" which in this case are mapped into Euclidean ones. The results and methodologies developed in the context of the happiness and urban studies keyword network could be useful for a systematic study of other complex evolving networks.

Keywords

Cities; complex networks; evolving graphs; ego-networks; happiness; urban studies

1 Introduction

Although sustainability science can be considered an emerging field of research[1], it actually occupies a central position in the social, economic and political agenda of many Western democracies. However, a genuine transition towards sustainability has not yet begun (Helne & Hirvilammi, 2015) and the concept has been relegated to a position of secondary or tertiary significance (Brown, 2016), many times seen as an empty signifier (Laclau, 2005) or even a plastic word (Poerksen, 1995). Approaches such as sustainable development or green economy seem to have failed to deliver a halt in the worsening of planetary health or the eradication of poverty and inequality (Kothari, Demaria, & Acosta, 2014). In fact, inequality and unsustainability have clearly increased by the recent phase of capitalism's accelerated expansion (Harvey, 2014). One possible answer to this failure are the complexities encountered when economy is considered as embedded in a wider social and biophysical system (Dodds, 1997). But at the root of this problem stand the many difficulties associated to the definition and measurement of the global condition of an individual or a group, being it termed happiness, subjective well-being, life satisfaction or positive affect, to name just a few of the existing close-related terms in the literature. As a global condition, this definition must include social, economic, psychological, spiritual or even medical states (Kullenberg & Nelhans, 2015). It is thus necessary to enrich the understanding of concepts like the ones previously mentioned on the basis of a relational paradigm, in which the dependency of human well-being on the health of the ecosystems is internalised (Helne & Hirvilammi, 2015). In recent years, and now for more than half of the population of the earth (United Nations Population Division, 2014), this ecosystem has been increasingly transformed into an urban one. Although urban contexts and cities can be considered from their origins the engines of human innovation (Glaeser, 2011), they are also characterised by important problems which have become central political issues (Davis, 2006; El Araby, 2002; Yafei Liu, Dijst, & Geertman, 2015; Wissink, Schwanen, & van Kempen, 2016), such as segregation, neighbourhood degradation, socio-economic deprivation and inequities in health, well-being and health-care accessibility. Cities are "the biggest, non-genetic influence on how

[1] http://sustainability.pnas.org/

healthy" we are (Buettner, 2008) and the influence of their environmental and built factors in the quality of life and aging of their inhabitants has been widely demonstrated (Steptoe, Deaton, & Stone, 2015):

- Green open cities that allow sport activity positively affect the brain and cognition (Hillman, Erickson, & Kramer, 2008).
- There is a positive correlation between cardiorespiratory fitness and cognitive function (Zhu et al., 2014) and a negative one between physical activity and cognitive decline (Sofi et al., 2011).
- Environments which promote social activity increase emotional health (Morrow-Howell, Hinterlong, Rozario, & Tang, 2003).
- Stressful environments are positively correlated with cerebral infarcts (Yu et al., 2015) and life shortening (Epel et al., 2004).

The measure of a society's health is also reflected on how well it takes care of the new generation (Benson, 2006). Nevertheless, the options that our built environment is giving in order to consider this perspective are increasingly limited (Jacobs, 1961). For example, among the twenty fundamental external resources detected to foster and build developmental assets for adolescents[2], 40% of them depend, directly or indirectly, on the built environment like: caring neighbourhood, caring school climate, community values for the youth, service to others, safety (at home, school, and in the neighbourhood), school and neighbourhood boundaries, high expectations, creative activities, youth programs (i.e., sports, clubs, or school and/or community organisations) and time at home.

Where we live affects all aspects of our life and thus our happiness (Florida, 2009): who we know, the "affective markets" in which we participate and the jobs, social networks and careers we have access to. The subjective happiness of the citizen consists of the harmonious satisfaction of three great needs or aspirations: (1) to live comfortably and safely, (2) to maintain pleasant social relations and (3) to feel that the vital possibilities increase[3]. As Marina suggests (2016), a city is considered "talented" if it is able to help meet

[2] http://www.search-institute.org/content/40-developmental-assets-adolescents-ages-12-18
[3] http://ciudadescontalento.com

those expectations by offering quality public services, favouring successful ways of coexistence and solving conflicts, and offering more options to expand their intellectual, emotional, cultural or economic possibilities (Marina, 2016).

Concepts such as liveability, living quality, living environment, quality of place, residential perception and satisfaction, have been introduced and transformed into indicators to evaluate the residential and living environment (Kamp, Leidelmeijer, & Marsman, 2003). These different and at the same time closely connected concepts find their origin in the various research and policymaking traditions of health and safety. In this sense terms such as quality of life, which has been in the development discourse for some time now, and sustainability, do overlap and are often used as synonyms of well-being, residential satisfaction or urban physical environment. This overlapping makes it clear that measuring happiness and other related concepts in cities and the urban environment is difficult, as the aspects to be measured are disputed and how are they related to each other is still unclear. The analysis of the happiness field has been approached by numerous researchers during the past years who studied concepts such as quality of life (see (Marans, 2012; Veenhoven, 2000)), happiness (see (Di Tella & MacCulloch, 2006; Easterlin, 2003; Layard, 2005; Veenhoven, 1997)), (subjective) well-being (see (Diener, 1994; Diener, Suh, Lucas, & Smith, 1999; Dolan, Layard, & Robert, 2011; Layard, 2010; Veenhoven, 2007)) and life satisfaction (Cummins, 1996; Diener, Inglehart, & Tay, 2013), but usually from a partial and more conceptual point of view. Although there have been numerous attempts to measure and analyse the factors that affect the quality of life in cities and regions (Ballas, 2013) and to construct alternative, non-monetary indices of social and economic well-being in urban planning (Khalil, 2012), how happiness concepts have penetrated urban planning, at which pace, and how they have been included in the urban studies field has not been assessed yet in the literature.

In order to obtain the connectivity graph that links happiness with other related concepts in the urban environment, we make use of complex networks science to map the temporal evolution and penetration process of the fields of happiness and urban studies into dynamic networks, obtained by paper keywords co-word analysis. The paper is organised as follows. Our database and methodology are explained in the

Materials and Methods section. In the Results section, and with the objective of quantitatively modelling the emergence of happiness in urban planning, we present first an analysis of the keywords of papers related with happiness studies. Once the evolution of the structural features of this network have been analysed, a second analysis of the keywords of papers related with urban studies that include particularly central keywords from the first network is performed. In the Discussion section, and in order to suggest an explanation to our results, we present a very simple spatial network model that reproduces significantly well this penetration process as a function of a "conceptual" distance that the model turns into an Euclidean one. We finish with the Conclusions section, where we recap and define some possible further work.

2 Materials and methods

Since the still relevant, and also criticised, account of the rise of new science by Thomas Kuhn (Kuhn, 1962), many attempts have been made in recent decades to characterise the advent, structure and evolution of new and/or well established scientific fields. With the advent of the indexing and availability of scholarly documents and literature, we have begun to quantitatively understand the process by which scientific fields, and even science itself, emerge (Luis M. A. Bettencourt & Kaiser, 2015; Börner, 2010, 2015). These quantitative methods commonly include one or a mixture of the following ones:

1. Population contagion dynamical models for the spread of ideas and the emergence and development of scientific fields (Luís M.A. Bettencourt, Cintrón-Arias, Kaiser, & Castillo-Chávez, 2006; Luís M A Bettencourt, Kaiser, Kaur, Castillo-Chávez, & Wojick, 2008; Luís M A Bettencourt & Kaur, 2011), where differential equations are numerically solved and adjusted to reproduce the temporal development of empirical data (i.e., authors, papers and dates of publication).
2. The structural analysis of networks of:
    a. Collaboration between scientists (Barabási et al., 2002; Luis M. A. Bettencourt & Kaiser, 2015; Luis M. A. Bettencourt, Kaiser, & Kaur, 2009; X. Liu, Bollen, Nelson, & Van de Sompel, 2005; Newman, 2001), where two scientists are considered connected if they have co-authored one or more papers together.

b. Connectivity between articles, in order to detect communities, fields or disciplines. In this case, articles can be connected with either of the following two ways:
    i. By means of the paper's references list:
        1. If they are cited in the same bibliographic list, a methodology known as co-citation coupling analysis (Small, 1973).
        2. If they share common references, a methodology known as bibliographic coupling analysis (Kessler, 1963). This methodology is considered more advantageous, since it gives equal weight to all published papers (whether cited or not), it can be applied to recent papers (which have not yet been cited) and links are established on the basis of the author's own decisions rather than retrospectively from other scientists' citations (Grauwin et al., 2012).
    ii. By means of words (in the paper or keywords), a methodology known as co-word analysis (Callon, Courtial, & Laville, 1991; Callon, Courtial, Turner, & Bauin, 1983). This methodology assumes that a paper's keywords constitute an adequate description of its content or, the links the paper established between problems (Ding, Chowdhury, & Foo, 2001).

In the structural analysis of these networks, communities are finally detected by modularity measures (Newman, 2002) and information about these communities is retrieved by means of qualifiers on the nodes. They can also be extended to generate different maps using co-occurrence of authors, keywords, institutions, etc. (Grauwin & Jensen, 2011).

The scientific research in human happiness has become an integrated line of inquiry throughout various disciplines. The impact of happiness studies has grown in importance during the last twenty years, but almost no attempts have been made yet to organise and map the scientific research contexts in which happiness studies have either penetrated pre-existing disciplines or become a core scientific activity. With the aim of analysing the historical development of the field itself and related journals, Kullenberg (2015) is the only reference found that uses bibliographic coupling to create clusters from a dataset of articles that included Web of Science topics searches based on four terms: happiness, subjective well-being, life satisfaction and positive affect, identified as core concepts in the field after a systematic literature review (Kullenberg & Nelhans, 2015). Results show that “happiness studies” has “emerged in many different disciplinary contexts and progressively been integrated and standardised” to even become an “autonomous field of enquiry”.

For this paper we adopted a co-word analysis. The reasons are multiple. Connectivity between articles by means of the paper’s references list, be it co-citation or bibliographic coupling, implies that when an author cites an article, he or she “creates its meaning”: the citation adopts “a symbolic dimension” (Kullenberg & Nelhans, 2015). This is a very strong assumption, since references lists rely on people openly citing papers rather than creating meanings. Besides, most citations are just copied from other papers, once a citation has reached a critical threshold, and they are not always read by the author who cites them (Newman, 2010). On the other hand, a remarkable result coming from the quantification process of emerging scientific contexts shown in the literature is that a definite scientific field seems to emerge only once there exists a critical amount of commonly shared set of (a) research questions, (b) concepts, and (c) methods that allow multiple authors to cooperate and collaborate (Luis M. A. Bettencourt & Kaiser, 2015). Surprisingly enough, research questions, concepts and methods, which are normally coded into keywords and words in the papers, have been traditionally ignored in these studies. The co-word analysis is an important bibliometric approach based on co-occurrence analysis and has been widely applied to illustrate how concepts, ideas, and problems within a given scientific field interact and to explore the concept network within the relevant field (see (Yong Liu, Li, Goncalves, Kostakos, & Xiao, 2016) and references therein). It has been used in the literature for mapping conceptual networks of disciplines like consumer behaviour research (Muñoz-Leiva, Viedma-del-Jesús, Sánchez-Fernández, & López-Herrera, 2012), patent analysis (Chang, Wu, & Leu, 2010), urban sustainability concepts (Fu & Zhang, 2017) or biology (An & Wu, 2011) and education (Ritzhaupt, Stewart, Smith, & Barron, 2010), to name a few.

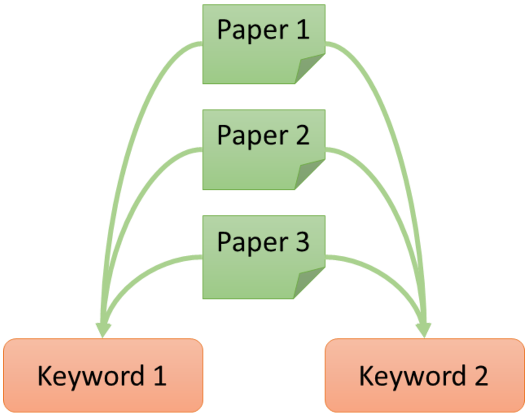

Figure 1 Keywords are connected if they appear in the same paper. The weight of the connection depends on the probability of co-occurrence.

Here we consider a network formed by keywords as nodes. Two keywords are connected if they appear in the same paper, and the weight of the link between the two keywords depends on the probability of co-occurrence of those two keywords across the various papers (Fig. 1). The weight is normalised as a bibliographic coupling (Kessler, 1963):

$$w_{i,j} = \frac{|P_i \cap P_j|}{\sqrt{|P_i||P_j|}} \quad (1)$$

where P_i is the set of papers that contain keyword i, and P_j is the set of papers that contain keyword j. By definition $w_{i,j} \in [0,1]$, is equal to zero when i and j do not share any paper and is equal to one when their sets of papers are identical. Thus constructed, the structural analysis of this network is a proxy of the conceptual structure of a specific discipline. It allows a time-series record of the changes that occurred in the conceptual space and it can reveal patterns and trends in a specific discipline by measuring the association weight of representative terms in relevant publications (Ding et al., 2001).

Assuming, as Kullenberg and Nelhans suggest (2015), that “happiness studies” has become an “autonomous field of enquiry” (Kullenberg & Nelhans, 2015) and in order to create the “happiness studies” network, we have assembled papers from the three ISI-JCR indexed journals related with quality of life, well-being and happiness: Journal of Happiness Studies (J HAPPINESS STUD), Journal of Positive Psychology (J POSIT

PSYCHOL) and Applied Research in Quality of Life (APPL RES QUAL LIFE), all of them addressing the conceptualisation, measurement, explanation and evaluation of happiness, well-being, human satisfaction, human development, wellness and quality of life. All items in the collection are publications written in English between 2000 and 2016[4]. Although considering publications in English only is a limitation, it represents by far the largest component of the scholarly literature. It also ensures consistency of records and facilitates automatic text parsing. In order to measure the penetration of this field into the urban studies one, a second search is conducted, this time using the most connected keywords from the previous network. The Scopus database records have been adopted here as they were found to have more complete and easy downloadable data, including available addresses for publications from which we extracted (via parsing of text addresses) city and nation of authors' institutions. Years of publication and journals, which we matched to ISI disciplines, were also extracted from each record. The focus was on the 2015's indexed Journals of the Urban Studies Category of ISI Web of Science (see Supplementary material 1 for the complete list). Similar titles not corresponding to indexed Journals of this category were excluded (see Supplementary material 2 for the search script).

The evolution of the structural features of the networks has been quantified using the following network metrics:

- **Average degree and degree distribution.** A key property of a node is its *degree*, representing the number of links it has to other nodes. We denote k_i the degree of node i in the network. In an undirected network with N nodes (i.e., size of a network), the total number of links L can be expressed as the sum of the node degrees

$$\boldsymbol{L = \frac{1}{2}\sum_{i=1}^{N} k_i} \qquad (2)$$

For an undirected network, its *average degree* is defined as

[4] J HAPPINESS STUD is the only Journal existing since 2000. J POSIT PSYCHOL and APPL RES QUAL LIFE made their appearance in 2006. Nevertheless, for abbreviation, we will mention that our period span is between 2000 and 2016.

$$\langle \boldsymbol{k} \rangle = \frac{\mathbf{1}}{\boldsymbol{N}} \sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{N}} \boldsymbol{k}_{\boldsymbol{i}} = \frac{\mathbf{2}\boldsymbol{L}}{\boldsymbol{N}} \tag{3}$$

The degree distribution p_k is giving the probability that a randomly selected node in the network has k links. Since p_k is a probability, it must be normalized, i.e. $\sum_{k=1}^{\infty} = 1$. For a fixed network of size N, the degree distribution is the normalised histogram $p_k = \frac{N_k}{N}$, where N_k is the number of degree k nodes. Networks for which p_k has a power-law tail, are known as scale-free networks (Barabási & Albert, 1999).

- **Clustering coefficient.** The local clustering coefficient captures the degree to which the neighbours of a given node link to each other (Watts & Strogatz, 1998). For a node i with degree k_i the local clustering coefficient is defined as

$$\boldsymbol{C}_{\boldsymbol{i}} = \frac{\mathbf{2}\boldsymbol{L}_{\boldsymbol{i}}}{\boldsymbol{k}_{\boldsymbol{i}}(\boldsymbol{k}_{\boldsymbol{i}} - \mathbf{1})} \tag{4}$$

where L_i represents the number of links between the k_i neighbours of node i. Here we use the average clustering coefficient of a network $\langle C \rangle$ as

$$\langle \boldsymbol{C} \rangle = \frac{\mathbf{1}}{\boldsymbol{N}} \sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{N}} \boldsymbol{C}_{\boldsymbol{i}} \tag{5}$$

- **Average path length and diameter**. Most networks are built to ensure connectedness. In an undirected network two nodes i and j are connected if there is a path between them on the graph. A path is a route that runs along the links of the network, its length representing the number of links the path contains. The shortest path between nodes i and j is the path with fewest number of links. It is also called distance, denoted d_{ij} or simply d. In an undirected network $d_{ij} = d_{ji}$. The network diameter, denoted d_{max}, is the maximal shortest path in the network, the largest distance recorded between any pair of nodes. The average path length, denoted by $\langle d \rangle$, is the average distance between all pairs of nodes in the network.

3 Results

3.1 “Happiness” network

Up until year 2016, our “happiness studies” dataset contains 1607 records: 778 (48%), 442 (28%) and 387 (24%) from J HAPPINESS STUD, J POSIT PSYCHOL and APPL RES QUAL LIFE, respectively (Fig. 2). We observe an increase in the cumulative number of published articles per year which follows an exponential function of the form $y\sim\exp(\alpha t)$, where t is time, with an exponential parameter $\alpha = 0.27 (R^2 = 0.97)$, in accordance to other several cases of emergence of new scientific fields (Luis M. A. Bettencourt & Kaiser, 2015). The cumulative number of keywords for the “happiness” network (Hn) reaches a value of 3491 for year 2016, and it follows a similar growth exponential trend, with an exponential parameter $\alpha = 0.23$ ($R^2 = 0.98$).

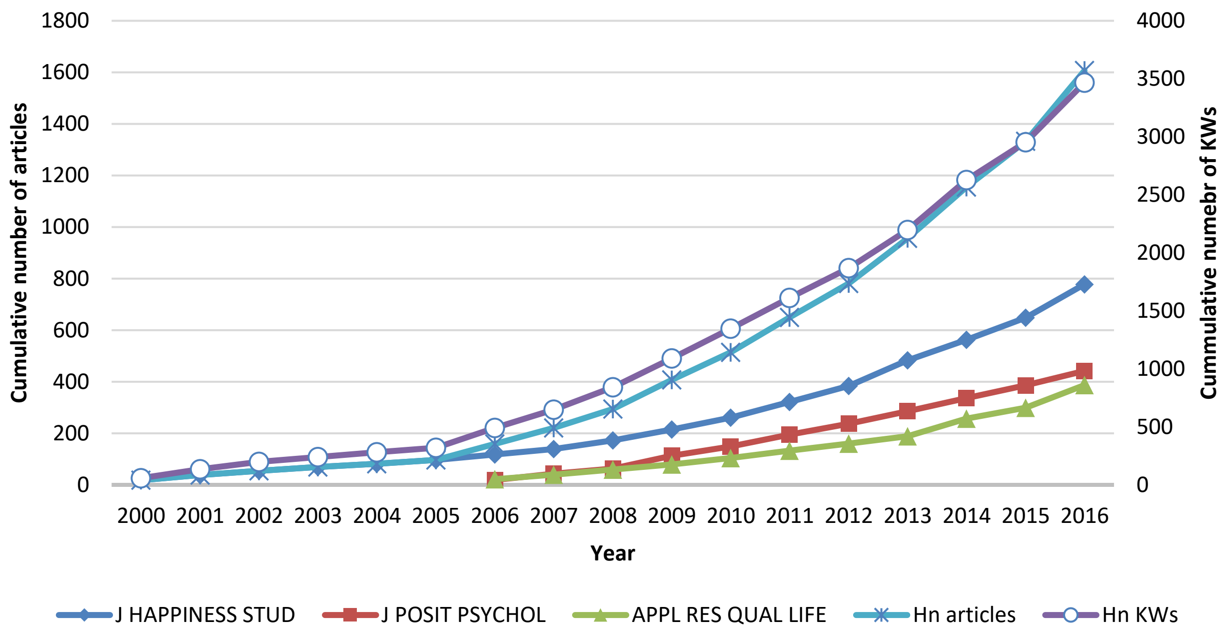

Figure 2 Cumulative number of articles (per journal and in total) and unique keywords (circles), per year.

The evolution of the topology of Hn in terms of four commonly used network centrality indices (i.e., degree, diameter, average path length and average clustering coefficient) and the percentage of nodes in the connected component (i.e., the subgraph in which any two vertices are connected to each other by paths) is shown in Figure 3, panel (i). Its topology is constantly dominated by a giant connected component, which contains between 88% and 95% of the nodes (i.e., keywords) through the years. The average degree $\langle k \rangle$ increases from $\langle k \rangle = 7.66$ in year 2000 to $\langle k \rangle = 9.14$ in year 2016. Diameter d and average path length ℓ

increase as well over time with the number of new nodes added, but they seem to stabilise their values from year 2011 onwards. The clustering coefficient C decreases slightly, from 0.904 to 0.867 in year 2013, where it keeps stable up to 2016.

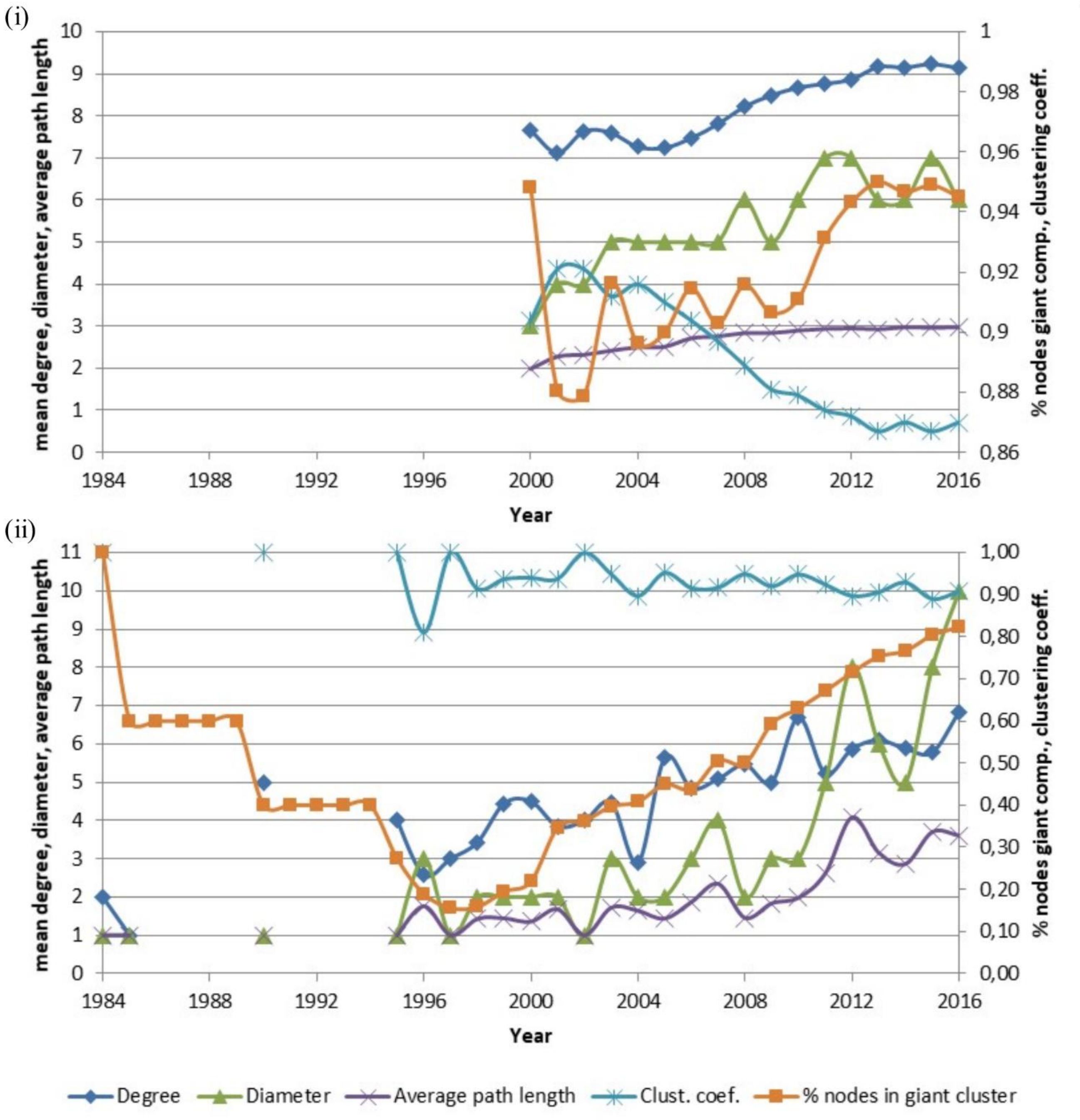

Figure 3: Emergence of Hn (i) and UHn (ii) in terms of mean degree, % of nodes in giant connected component, diameter, average path length and clustering coefficient.

At year 2016, the Hn degree cumulative probability distribution appears fat-tailed, with the most connected nodes being happiness (H), life-satisfaction (LS), subjective well-being (SWB), well-being (WB), quality of life (QoL) and positive psychology (PP) (see Figure 4 and Table 1). Hn shows a slightly negative nearest neighbour degree correlation (results not shown in the text), implying a disassortative behaviour where hubs tend to avoid each other, linking mainly to small-degree nodes, and making communities of similar keywords difficult to appear (Barabási, 2016).

Table 1: Most connected elements in J HAPPINESS STUD, J POSIT PSYCHOL, APPL RES QUAL LIFE, Hn and UHn, in year 2016 (cumulated data from 2000 and 1984 respectively). Degree shown in parenthesis.

APPL RES QUAL LIFE	J HAPPINESS STUD	J POSIT PSYCHOL	Hn	UHn
Quality of life (224)	Happiness (535)	Positive psychology (178)	Happiness (652)	Quality of life (194)
Life satisfaction (102)	Life satisfaction (324)	Well-being (167)	Life satisfaction (463)	Well-being (154)
Subjective well-being (69)	Subjective well-being (319)	Happiness (123)	Subjective well-being (429)	Health (81)
Happiness (66)	Well-being (228)	Life satisfaction (111)	Well-being (401)	Ecosystem services (77)
Well-being (61)	Quality of life (91)	Subjective well-being (96)	Quality of life (309)	Urban planning (68)
Health-related quality of life (61)	Positive affect (90)	Meaning/ positive emotions (87)	Positive psychology (244)	Sustainability (65)

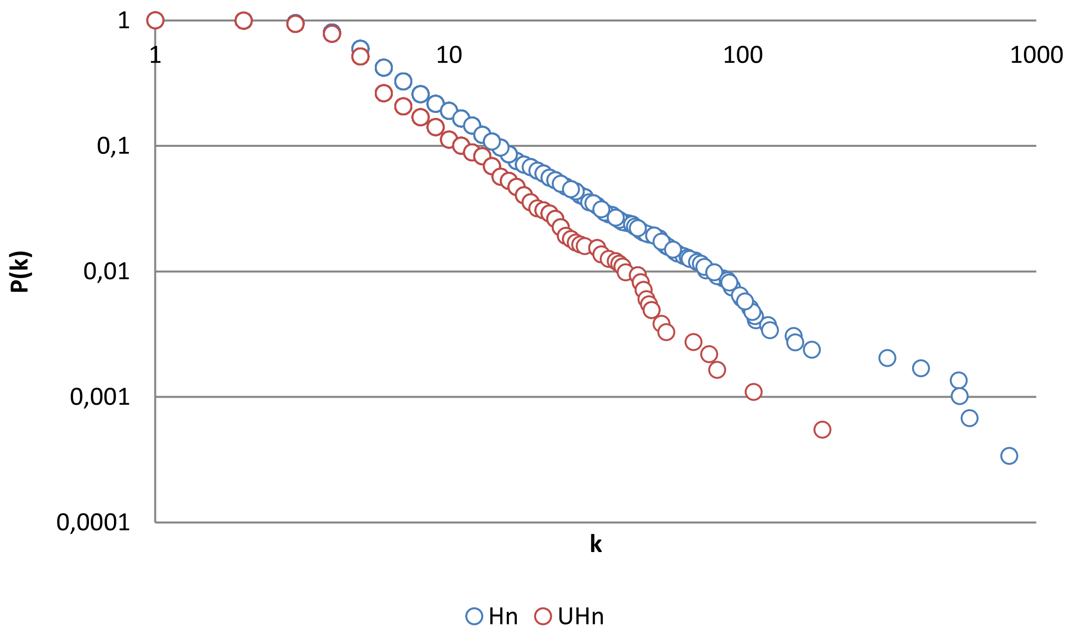

Figure 4: Cumulated degree probability distribution P(k) for Hn (blue dots) and UHn (red dots) in log-log plot (year 2016).

Finally, we are interested in detecting possible pairwise correlations among keywords using weight (1) and weighted degree, also known as node strength, and defined as the sum of weights attached to ties belonging to a node (Barrat, Barthélemy, Pastor-Satorras, & Vespignani, 2004). As shown in Fig. 5, node degree and node strength are not correlated, and nodes with extremely high degree values (Table 1, column Hn) are characterised by relatively low strengths. The variability in the weighted degree is reduced at minimum for the most connected nodes: in descending order, H ($k = 652$), LS, SWB, WB, QoL and PP ($k = 244$). Special mention deserves WB, with $k = 336$ but $s = 0.1$ (yellow in the graph), which indicates a very low connectivity in terms of co-occurrence with the rest of the keywords. The fact that the connectivity is not dominated by especially strong links between keywords is shown by the probability distribution of edge weights (Fig. 5, inset), which fits an exponential function, far from any fat-tailed distribution.

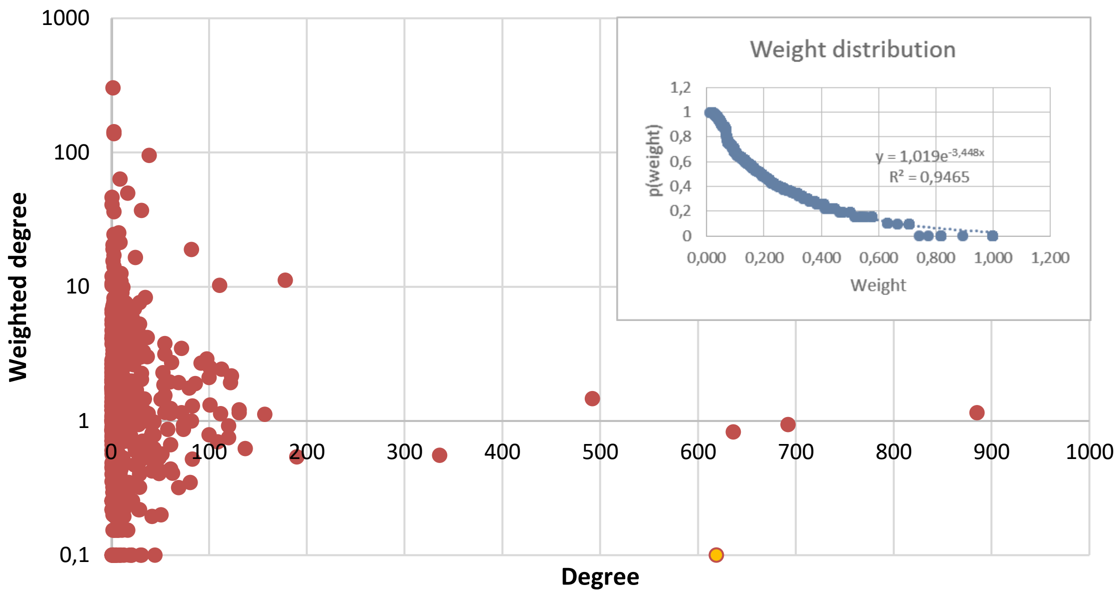

Figure 5: Topological degree vs. weighted degree and cumulated probability distribution of weights (inset) for the Hn.

3.2 "Urban-Happiness" network

The "urban-happiness" network (UHn) includes data from 551 published (or pre-published online) articles from the 39 journals indexed in the Urban Studies category of ISI Web of Knowledge (see Appendix A) between 1984 and 2016. Only articles with author keywords were considered. These articles were searched in the Scopus database using the words with maximum degree in Hn (Table 1, column Hn). From this dataset, a list of 1826 unique keywords related with happiness and urban studies categories was extracted, resulting in a network of 5737 edges (Fig. 6). As we can see, *QoL* is mostly connected with keywords such as *health*, *sustainability, housing* and *community development* while *WB* connects to *green space*, *physical activity* and *nature*. There appear also three additional important communities. The first one is dominated by *ecosystem services* and connected to keywords such as *social capital*, *biodiversity* and *urban ecology* among others. The second one is dominated by *urban planning* but has no other important keywords and the third one by *urbanization* and *LS* and it is where we can also find *H* and *SWB* among others. Positive psychology gave no search results in the bibliographic search of this study category.

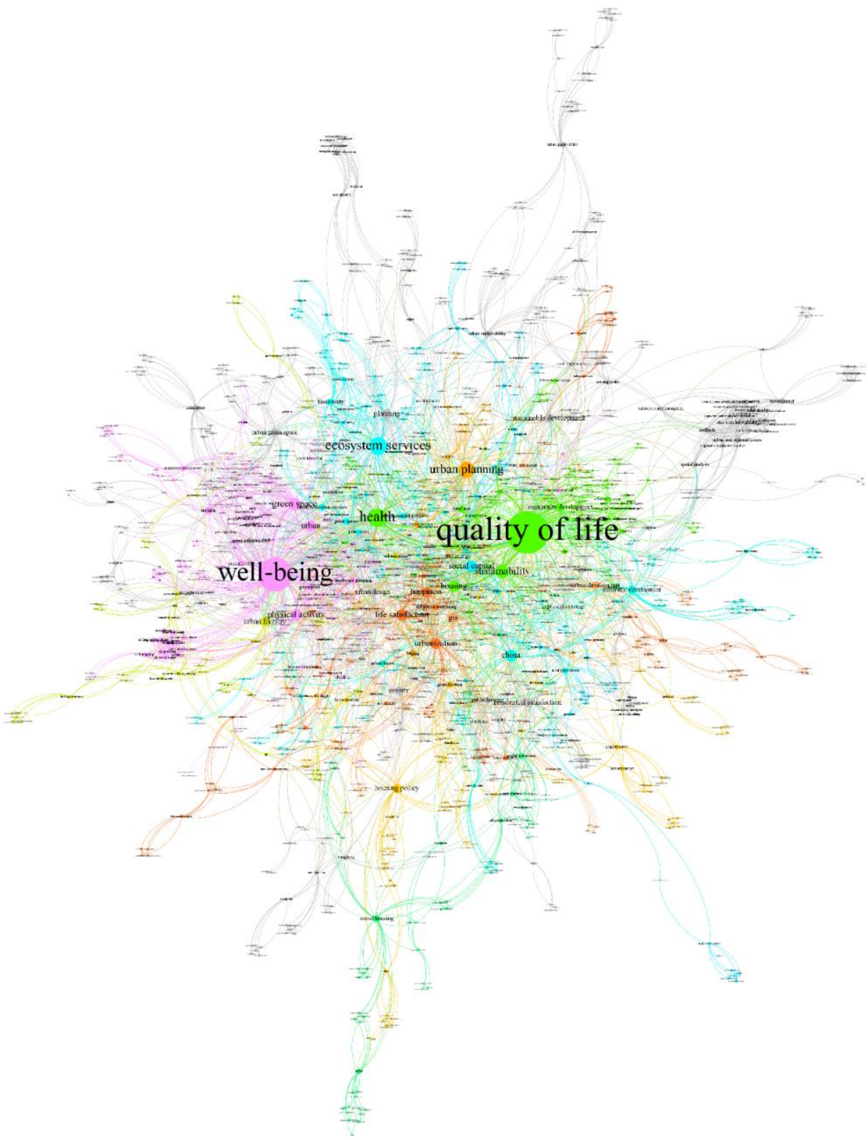

Figure 6: Overall aspect of the UH network. The size of a node is proportional to its degree and the colours represent the different clusters.

The evolution of the topology of UHn in terms of the same centrality indices used for the Hn case (i.e., degree, diameter, average path length and average clustering coefficient) and the percentage of nodes in the connected component is shown in Figure 3, panel (ii). In this case, although a primitive connected component appears in 1984, it is not until 1998 that the percentage of nodes in the giant connected component begins to increase, covering from a 15% of the total network to a 80% in 2016. The average degree $\langle k \rangle$, increases from $\langle k \rangle = 2.667$ in year 1998 to $\langle k \rangle = 6.828$ in year 2016. Here, diameter d and average path length ℓ increase more steeply than in the Hn case, but unlike this later, they do not display a stable behaviour over time. The clustering coefficient C decreases slightly, from 1.0 (where keywords appear as cliques in each paper) to 0.872 in 2016. Similarly to Hn, at year 2016, the degree cumulative probability distribution appears fat-tailed, with most connected nodes being QoL (194) and WB (154). In this case, though, and with degree values one order of magnitude lower than QoL and WB (Table 1, column UHn), the connectivity of UHn is ruled by “health” (81), “Ecosystem services” (77), “Urban planning” (68) and “Sustainability” (65). UHn shows no nearest neighbour degree correlation and uncorrelated strength and degree (results not shown in the text).

3.2.1 Ego-network analysis

The analysis of the temporal evolution of UHn offers the possibility to observe the coalescence of several urban fields around concepts related with the happiness one (Fig. 7). We observe the predominance of QoL and the late entrance of SWB and H, as late as year 2011.

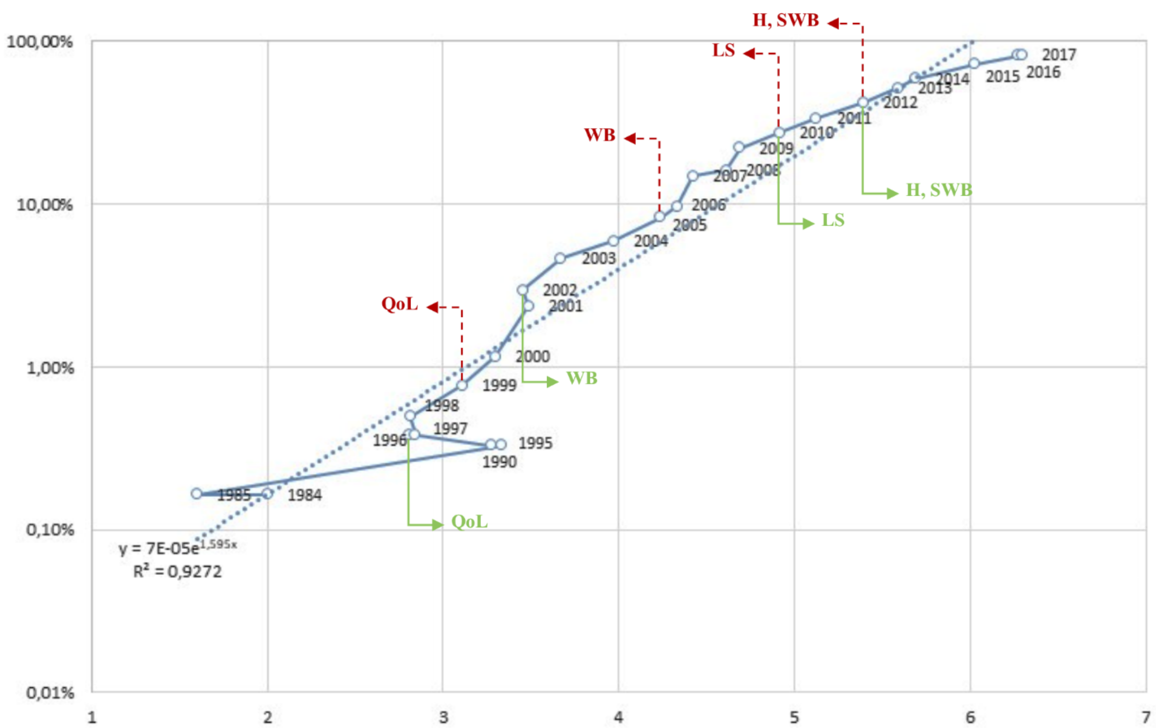

Figure 7: Percentage of nodes (cumulative) in the giant components as a function of <k>. Green arrows show the year of appearance of the most connected KWs of Hn in UHn and red dashed arrows the year of connection of these KWs to UHn’s giant component. As the graph is getting bigger over time, the KWs appear directly connected to the giant component.

In order to detect subfields and fine-grain our analysis, a modularity algorithm (Newman, 2002) has been run over the giant connected component of UHn, to select the groups including each one of the five most connected KWs of Hn (positive psychology (PP) gave no results in the bibliographic search).

- *QoL* appears in 1996 but does not connect to the giant component until 1999 (Fig. 7). It belongs to the biggest cluster and shares a triangle with *urban environment* and *information technology*. At the same time it is connected to *public housing*, *housing policy* and *urban transport* i.e., during this period of time it is mostly related to infrastructures. The 2005 snapshot shows that QoL network transforms to a more hierarchical structure while it continues forming the larger cluster of the giant component, while in 2009 QoL is generally connected to urban environment and information technology. In 2011, QoL network has a similar although more expanded form of that of the previous period, agglomerating a greater quantity of nodes. *Sustainability*, *urban planning* and *urbanisation* are some of the main concepts connected to it. At the end of 2016, QoL network shows a clear hierarchical form. High degree and centrality keywords such as *health*, *housing*, *sustainability*, *community development* and *economic development* are connecting it to important concepts that define it.
- *WB* appears in the graph in 2002. It does not connect to the giant component though until 2005. The graph during this period is dominated by two keywords, WB and *elderly.* In the 2009's snapshot WB has a dominant centrality shared with *landscape planning* and *recreation*, while it is connected to *leisure activities* and *healing environments*. In 2011, we observe that the initial triangle of the central elements is maintained although *landscape planning* and *recreation* of the previous period are replaced by *health* and *physical activity*. At the end of 2016, WB appears more related to the environment, and *green space*.
- *LS* enters the graph in 2009 and directly connects to the giant component. The entrance in its cluster is made externally, directly depending from *urbanisation* and indirectly from the central concept of *urban planning*. In 2011 LS is still peripheral in the cluster containing it. *SWB* and *H* join both the graph and the giant component in 2011. They both form part of the cluster dominated by *urban design*. H

appears to have a higher centrality than SWB. In the period between 1984 and the end of 2016, the biggest cluster is not anymore that of QoL. Instead, it contains LS, SWB and H. The three keywords are not central but connected to the rest of the graph through *urbanisation*, *social capital* and *urban design*.

Figure 8 show subgraphs related to the five main KWs coming from the previous stage (H network): QoL, WB, LS, SWB and H. The representation took place in five temporal snapshots, coinciding with those of the connection of each of the keywords in the giant component of the graph (see Figure 7). The snapshots of Figure 8 focus on the neighbours and the neighbours of neighbours of the KWs along with the connections between them. We observe a star-like structure which is repeated each time a KW enters the connected component, characterised by cliques (i.e., keywords in one particular paper) randomly distributed around hubs (i.e., most connected nodes).

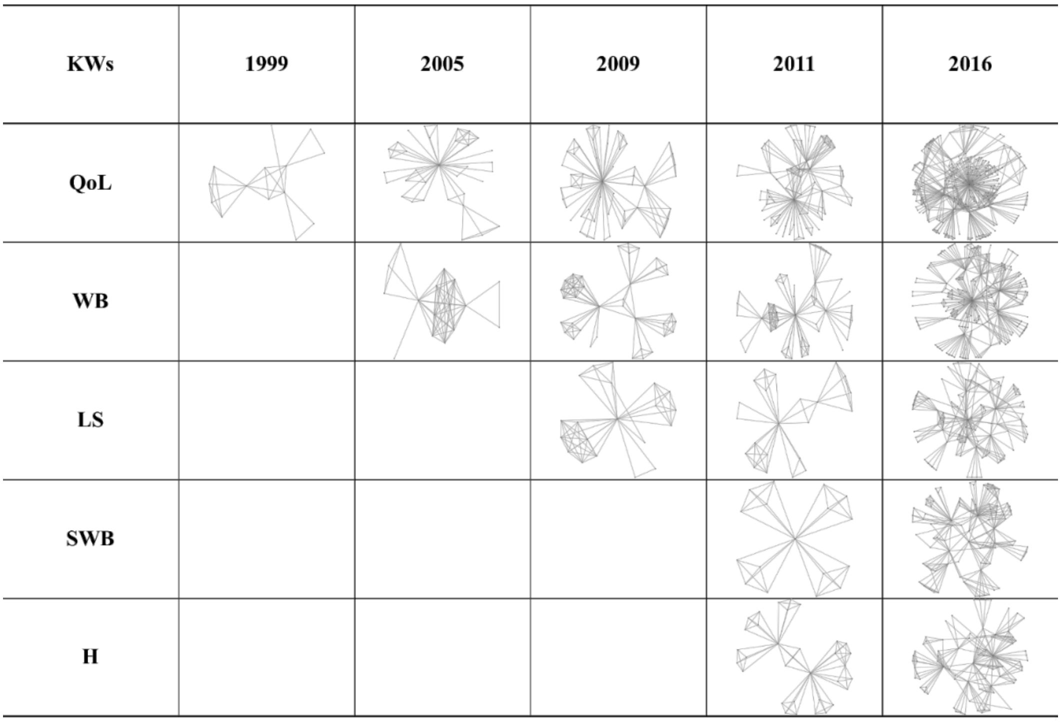

Figure 8: Evolution of the UHn ego-networks of the most connected nodes in Hn.

The temporal evolution of four global network indices (i.e., average degree $\langle k \rangle$, diameter d, average clustering coefficient $\langle C \rangle$ and average path length ℓ) for the ego-networks related with keywords QoL, WB, LS, SWB and H, show a striking similarity (Fig. 9). The rate of increase of $\langle k \rangle$ (Fig. 9, i) and d (Fig. 9, ii) is similar for each KW, the only difference being the point in time when that particular KW makes its entrance in the field. The average increase in $\langle k \rangle$ per year is $\Delta\langle k \rangle = 0.300$, while for the diameter is $\Delta d = 0.793$. The evolution over time of the average path length ℓ for QoL and WB (Fig. 9, iv) reaches a common value in logarithmic form, while the clustering coefficient shows more variability, since it depends on how first neighbour keywords of keywords are linked to each other.

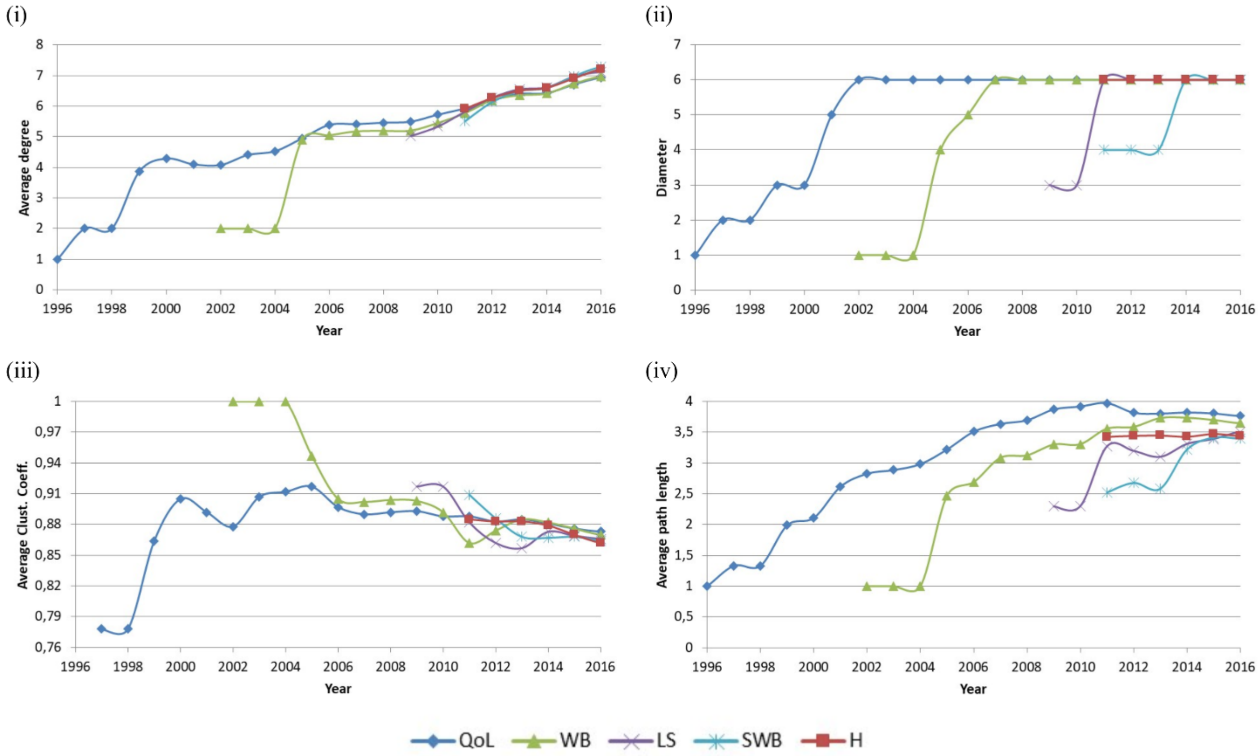

Figure 9: Temporal evolution of four global network indices (i.e., average degree, diameter, average clustering coefficient and average path length) of the ego-networks related with keywords QoL, WB, LS, SWB and H.

Finally, and in order to detect how the connectivity of the network ends up dominated by hubs, we plot the evolution over time (years 1999, 2005, 2009, 2011 and 2016) between average clustering coefficient $\langle C \rangle$ and degree $\langle k \rangle$ for the ego-networks related with keywords QoL, WB, LS, SWB and H (Fig. 10). It shows a non-linear power law correlation of the form $k{\sim}c^{-\alpha}$, where $\alpha = 1.035$ ($R^2 = 0.89$), with clustering and degree decreasing and increasing in time respectively.

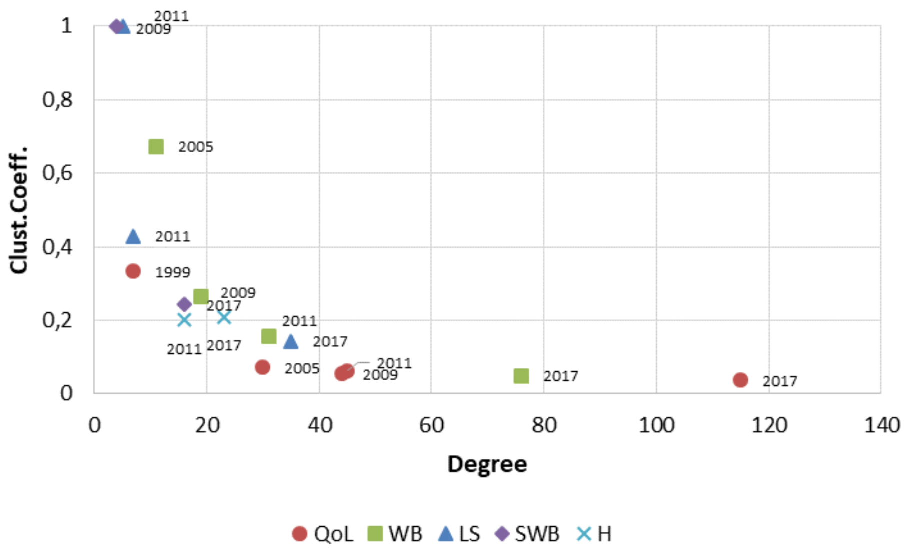

Figure 10: Evolution and correlation over time between average clustering coefficient and average degree, for keywords QoL, WB, LS, SWB and H.

4 Discussion

The exponential increase in the cumulative number of articles and keywords in Hn (Fig. 2) follows a trend similar to those of emerging new scientific fields (Luis M. A. Bettencourt & Kaiser, 2015; Luis M. A. Bettencourt et al., 2009; Luís M A Bettencourt & Kaur, 2011). Simultaneously, both the graph diameter and the average path length grow, and eventually stabilise from year 2010 onwards (Fig. 3). The network as a whole undergoes a kind of transition in year 2000, where the giant component begins to include most of the nodes of the network. The increase in the average degree over time means in practice that a densification process is at play. Although in other cases the network diameter d tends to decrease as a graph grows (Leskovec, Kleinberg, & Faloutsos, 2007), so it implies a more tightly woven connected component, in this case, as in collaboration graphs for scientific and technological fields for example (Luis M. A. Bettencourt et al., 2009), Hn shows an initial fast growth in its diameter, which tends to stabilise and stay approximately constant at $d{\sim}6-7$. Thus, even as the keyword graph densifies, the graph stays globally connected such that the diameter of its largest component does not change measurably. However, this process comes essentially from linear connections between keywords, and not from local increase in connectivity. The decreasing trend over time followed by the average clustering coefficient and the disassortative behaviour of the network suggest this trait. This behaviour deviates from other examples where the establishment of central conceptual or experimental techniques are primordial. In this case, new concepts do not necessarily need to be closely related to others in order for them to appear in the Hn graph. In fact, the homogeneity in link weights (Fig. 5, inset) imply that weighted degree and degree are not correlated: keywords connect to other keywords, but this connectivity implies no co-occurrence. In other words, the most connected words in Hn are used indistinctly to categorise many different parts of the field, but not univocally: these are used as plastic words and with a global significance. This behaviour is not observed, for example, in social networks, where degree and strength (and even their probability distributions) can be highly correlated (Panzarasa, Opsahl, & Carley, 2009).

Given this particular structural character in Hn, the capacity of words such H, QoL, SWB, etc., to penetrate other fields should be significant, as it happens in general with words able to be twisted to fit various circumstances, also known as plastic words (Poerksen, 1995), or those with disputed definitions (Nature, 2008). Indeed what we observe in UHn is a network which keeps on growing, with irregular evolution but constantly increase of its structural measures (Fig. 3, ii). Although the network as a whole undergoes a transition in year 1998, the current giant component is still growing and it includes only slightly over 80% of the nodes. The increase in the average degree over time means that a densification process is also at play, but its diameter is far from stabilising, and it grows at a higher rate than its average path length. Thus, even as the UHn graph densifies, the distance between concepts increases further, suggesting again a process which comes essentially from linear connections between keywords, and not from an increase in local (i.e., neighbourhood) connectivity.

4.1.1 Network model

In order to explain the evolution of the structure of the UHn, we present a very simple model of a spatial network which maps spatial Euclidean distances onto categorical (i.e., conceptual) ones.[5] Spatial networks have nodes and edges which are constrained by some geometry and are usually embedded in a two- or

[5] The model has been implemented in NetLogo™ 6.0. The descriptive (ODD) information of the model can be found in the "Info" tab. It can be downloaded from http://tinyurl.com/ycdwpprp

three-dimensional space (Barthélemy, 2011). Although most research in this field has been focused in searching optimal topologies (Barrat et al., 2004; Luo, Pagani, & Rosas-Casals, 2016; Marza, Dehghan, & Akbari, 2015), our model aims at reproducing the connectivity pattern of keywords in papers, as a function of the Euclidean spatial distance that acts as the separation (i.e, virtual distance) between academic/scientific fields. The model starts with a node (known as *keyword* 0) placed at the centre of a squared two dimensional space, linked with other nodes that act as the keywords of the same paper. At every time step t a new paper is located at a randomly chosen position governed by the parameter *paper-radius* (Fig. 11). This parameter models the virtual distance between academic fields in terms of Euclidean distance between papers. In this sense, the distance among the keywords of one same paper, *kw-radius*, is inversely proportional to *paper-radius*. The higher the value this parameter takes, the more distance will exist between the keywords of two different papers, but more closely together the keywords of one particular paper will be. The connectivity between an already existing keyword and a new appearing one n_t at time t is established with decreasing exponential probability on the Euclidean distance d that separates them:

$$p(n_t, d) \sim exp(-d) \quad (6)$$

Finally, and in order to model the fact that keywords located far-away from the central one could be more similar than expected, a second parameter known as *redundancy* introduces a random probability of connection between two nodes at a distance less than *kw-radius*.

The results of the model for three different values of the parameter *paper-radius* and a *redundancy* value of 0.005 show qualitatively a transition between two kinds of networks (Fig. 17). On the one side, when *paper-radius* is low (*paper-radius* = 2), keywords appear in the same geographical zone. This is the case where papers appear in very specific and closely related, academic fields. In this case the average degree increases almost exponentially, while the diameter keeps on being reduced over time (Fig. 17, i). On the contrary, when *paper-radius* is high (*paper-radius* = 30), keywords appear separated from each other, in different and distant geographical (i.e., conceptual) zones. This is the case where papers emerge in very specific but unrelated, academic fields. In this case the average degree is kept constant and the diameter increases over time (Fig. 17, ii). At a value of essentially *radius-paper* = 10 (Fig. 17, iii) we obtain results that closely resemble the particular evolution of the individual keywords presented in Fig. 9. We observe a linear increase in the average degree, while the clustering coefficient decreases. The average path length approaches asymptotically a constant value, and the diameter increases suddenly and remains at a fixed value for the rest of the experiment. Finally, with this particular combination of values, the model also reproduces the behaviour shown in Fig. 10, that is a non-linear power law correlation of the form $k \sim c^{-\alpha}$, where $\alpha = 1.2$ ($R^2 = 0.96$), with clustering and degree decreasing and increasing in time respectively (results not shown in the text, but replicable and shown in the model).

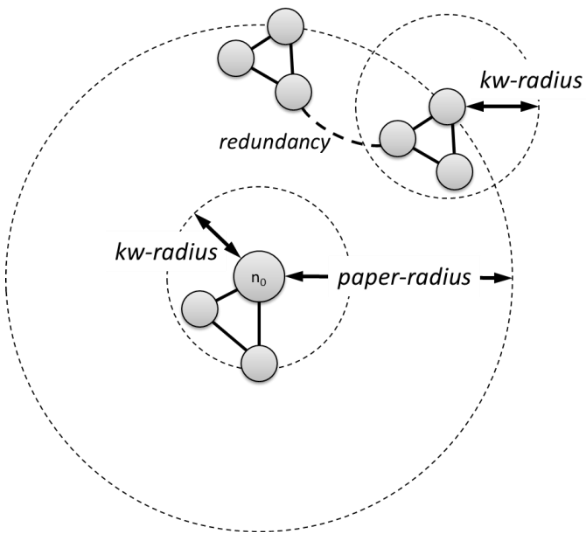

Figure 11: Papers as networks of keywords. The model creates networks (i.e., papers) with nodes as keywords, and uses (a) *paper-radius* as a parameter to map a "conceptual" distance into a Euclidean one, and (b) *kw-radius* (inversely proportional to *paper-radius*) as a parameter to locate the keywords of a paper at a certain distance.

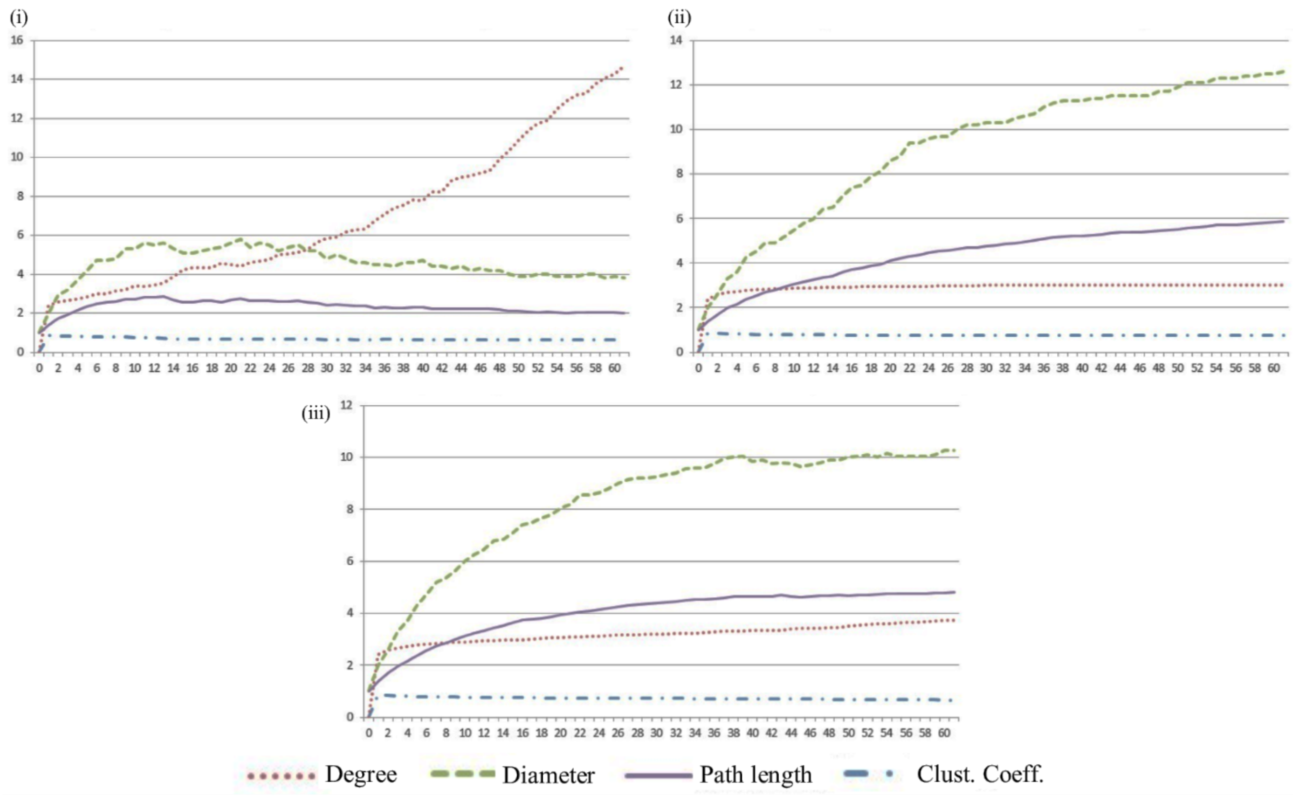

Figure 12: Results of the model for three different values of the model parameter. (i) *paper-radius* = 2, (ii) *paper-radius* = 30, (iii) *paper-radius* = 10.

The robustness of the model is suggested by how well it reproduces the real temporal behaviour of the ego-network of the keyword “happiness”, extracted from Hn (Fig. 13). The ego-network metrics of Figure 13 are the same for the rest of the most connected KWs (QoL, WB, LS and SWB) of Hn as they are since the beginning closely connected to the giant component. In this case, “happiness” appears in a field with similar concepts and short conceptual distances between keywords. Thus, its evolution over time should be more similar to that of Fig. 12 (i) than that of Fig. 12 (iii). Indeed, we observe a trend similar to the initial states of Fig. 12 (i), where average degree, diameter and average path length slightly increase, while average clustering coefficient decreases. The differences observed between the model and the Hn are mainly concentrated in the first one or two time steps of the model. This is because the model starts with only one KW (keyword 0) while the real network starts with much more KWs and connections. Some differences arise when the temporal scale of the model surpasses that of the real network. In particular, average clustering coefficient is decreasing following a small pace, maintained close to 0.9 for both networks. Average degree increases in both cases slowly in relation to time after the initial quick increase in the model. Diameter increases following a quicker pace than the rest of the metrics, stabilises and then slowly decreases. Average path length increases slowly and starts decreasing after the 22nd step in the model. Comparing the results on the five ego-networks of UHn (Fig. 9) with the model we observe similar results again with Fig. 12 (i). The similarity is most easily distinguishable when comparing with the QoL ego-network, which covers a more extended temporal span than the rest.

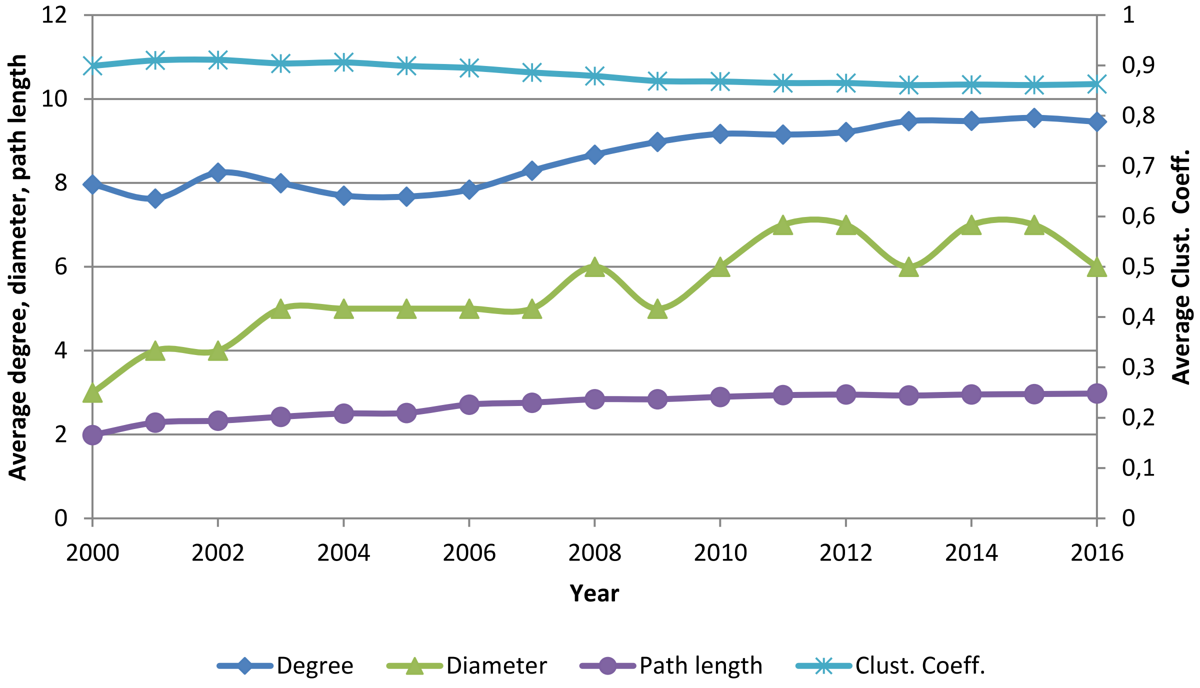

Figure 13: Evolution of the H ego-network in terms of mean degree, diameter, average path length and clustering coefficient.

5 Conclusions

Happiness field of studies has grown in importance during the past years englobing concepts such as quality of life, (subjective) well-being, life satisfaction and positive psychology. However, the level of penetration of this field inside other fields of interest has not yet been studied. In this paper we use co-word and complex networks analysis of scientific articles' keywords to map the temporal evolution of the fields of (i) happiness per se and (ii) happiness inside urban studies field. For the happiness field we have shown that its most connected words behave mostly as plastic words with a global and adaptive significance, as they are used indistinctly to categorise many different parts of the field, but not univocally. The fact that in the urban field

(UHn) and among the most connected words, after QoL and WB, we find “sustainability”, “ecosystem services”, “health” and “urban planning”, reinforce the plastic character of these concepts. They are all current trending topics, extensively spread to scientific and other communities, but with an overarching capacity. The level of penetration of these words to the Urban studies makes it difficult to think that they can be used with a commonly accepted meaning in their current form. Academia is supposed to be precise and measured in terms of definitions. But like “complexity”, “race” or “significant”, in the statistics field, words in the field of happiness seem currently to be vaguely defined and in need, at least, of adjectives.

In this paper we also study the topology of the dynamic networks related with the aforementioned fields, transforming conceptual distances into Euclidean ones in a spatial network model. Despite its simplicity, the model reproduces remarkably well the growth of ego-networks and different levels of penetrations, depending on the “conceptual” distance. How in general an alien conceptual field penetrates another and, in particular, how a field like happiness studies penetrates other seemingly unrelated fields, although clearly linked with sustainability, like economics, ecology, etc., is a matter of future work and research.

We believe that the results and methodologies developed in the context of the happiness and urban studies keyword networks could be useful for a systematic study of other complex evolving networks related with conceptual aspects of academic or other fields.

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Appendix A

NetLogo* implementation of the model: http://tinyurl.com/ycdwpprp

(*) U. Wilensky, "NetLogo." Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL., 1999.

Appendix B

Journals in Urban Studies category according to 2015 classification.

Journal ID	Journal
1	Cities
2	City and community
3	Economic development quarterly
4	Education and urban society
5	Environment and urbanization
6	EURE
7	European planning studies
8	European urban and regional studies
9	Habitat international
10	Housing policy debate
11	Housing studies
12	Housing theory and society
13	International journal of urban and regional research
14	International regional science review
15	Journal of architectural and planning research
16	Journal of contemporary ethnography
17	Journal of housing and the built environment
18	Journal of housing economics
19	Journal of planning education and research
20	Journal of planning literature
21	Journal of real estate finance and economics
22	Journal of the American planning association
23	Journal of urban affairs
24	Journal of urban economics
25	Journal of urban history
26	Journal of urban planning and development
27	Journal of urban technology
28	Landscape and urban planning
29	Open house international
30	Real estate economics
31	Regional science and urban economics
32	Urban affairs review
33	Urban design international
34	Urban education
35	Urban forestry and urban greening
36	Urban geography
37	Urban lawyer
38	Urban policy and research

39	Urban studies

Appendix C

Data search in Scopus - script

(SRCTITLE ("Landscape and Urban Planning" OR "urban forestry and urban greening" OR "journal of planning literature" OR "habitat international" OR "cities" OR "european urban and regional studies" OR "international journal of urban and regional research" OR "journal of urban economics" OR "urban studies" OR "journal of the american planning association" OR "housing theory" OR "urban geography" OR "environment and urbanization" OR "european planning studies" OR "journal of planning education and research" OR "international regional science review" OR "housing policy debate" OR "regional science and urban economics" OR "city and community" OR "housing studies" OR "journal of urban technology" OR "urban education" OR "journal of urban affairs" OR "urban affairs review" OR "economic development quarterly" OR "journal of contemporary ethnography" OR "journal of urban planning and development" OR "real estate economics" OR "journal of housing and the built environment" OR "journal of real estate finance and economics" OR "urban policy and research" OR "journal of architectural and planning research" OR "journal of housing research" OR "journal of architectural and planning research" OR "journal of housing economics" OR "urban lawyer" OR "urban design international" OR "education and urban society" OR "eure" OR "journal of urban history" OR "open house international") AND TITLE-ABS-KEY ("happiness" OR "life satisfaction" OR "satisfaction of life" OR "satisfaction with life" OR "well-being" OR "wellbeing" OR "subjective well-being" OR "subjective wellbeing" OR "quality of life" OR "positive psychology")) AND DOCTYPE (ar OR re) AND (EXCLUDE (EXACTSRCTITLE , "Sustainable Cities And Society") OR EXCLUDE (EXACTSRCTITLE , "City Culture And Society") OR EXCLUDE (EXACTSRCTITLE , "City") OR EXCLUDE (EXACTSRCTITLE , "Demos Mexico City Mexico") OR EXCLUDE (EXACTSRCTITLE , "Architecture City And Environment") OR EXCLUDE (EXACTSRCTITLE , "Environment And Urbanization Asia") OR EXCLUDE (EXACTSRCTITLE , "Osaka City Medical Journal") OR EXCLUDE (EXACTSRCTITLE , "American City And County") OR EXCLUDE (EXACTSRCTITLE , "Business Of Sustainable Cities Public Private Partnerships For Creative Technical And Institutional Solutions") OR EXCLUDE (EXACTSRCTITLE , "Changing Social Geography Of

Canadian Cities") OR EXCLUDE (EXACTSRCTITLE , "City And Society") OR EXCLUDE (EXACTSRCTITLE , "City Landscape") OR EXCLUDE (EXACTSRCTITLE , "Decline Of Transit Urban Transportation In German And US Cities 1900 1970") OR EXCLUDE (EXACTSRCTITLE , "Electronic Products Garden City New York") OR EXCLUDE (EXACTSRCTITLE , "Ethnic Segregation In Cities") OR EXCLUDE (EXACTSRCTITLE , "Habitat Health And Development A New Way Of Looking At Cities In The Third World") OR EXCLUDE (EXACTSRCTITLE , "Making Of Citizens Cities Of Peasants Revisited") OR EXCLUDE (EXACTSRCTITLE , "Regenerating The Inner City Glasgow S Experience") OR EXCLUDE (EXACTSRCTITLE , "University Of Toronto Centre For Urban Community Studies Child In The City Report"))