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Technological Drivers of Urban Innovation: A T-DNA Analysis Based on US Patent Data

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Abstract: Fast urbanization leads to several challenges in many cities all over the world. Thus, urban innovation is considered a common approach to deal with such questions. Although technologies are important factors in urban innovation, the development of technologies over time, how they affect urban innovation, in which relationship they stand to each other, and how they can be evaluated in a system approach are still not clear. To answer these questions, in our study, a Technology-DNA (T-DNA) is applied to US patents, which represent the most developed market in the world. Our paper provides some theoretical points in urban innovation and a systematic classification of technologies in this field based on patent classes. In addition, this research shows technological drivers in different system levels in urban innovation, especially in the super-system (representing city infrastructures) in detail. Therefore, it may help researchers, managers, politicians, and planners to focus on important technologies and to integrate technological drivers in urban innovation in their plans.

Keywords: urban innovation; construction; patent analysis; Technology-DNA; infrastructure; technology dynamics

1. Introduction: The Need for Urban Innovation

Recently, in order to improve their living conditions, more and more people expect to move from the countryside to the cities. This fact has led to a considerable increase in urban population in the world [1–3]. According to Shahidehpour, Li, and Ganji [3], the number of people living in urban areas rose from 1 billion (about 30% of the world population) in the 1950s to approximately 3.9 billion (over 55% of the total population) at present. It is predicted that this number may reach 6.5 billion, which will make up about 70% of the global population, in 2050 [4]. Thus, the whole world is facing extremely fast development of urbanization which places an excessive burden on city infrastructures to satisfy a huge number of people's demands for 'energy, water, transportation, education, healthcare, and safety' [5,6]. As a matter of fact, although only about 5% of the total land mass in the world is occupied by cities, people in urban areas consume 75% of natural resources and emit 70% of greenhouse gas of the whole world [3]. That is the reason why urbanization creates serious problems such as: air pollution; traffic jams; inadequate resources; issues in waste management, health care, or downgraded facilities [7–9]; and natural disasters [10]. Furthermore, the expansion of urban areas into rural ones to gain more spaces for their large population, streets, businesses, manufactures, etc. results in several problems in the countryside like poor balance of natural habitats, increases in traffic, noise, and pollution [8,11].

Hence, to cope with such shortcomings, it is recommended to apply urban innovation—integration of many innovations to develop city infrastructures for sustainable development [3]. Urban innovation is a noticeable phenomenon in many countries all over the world in the 21st century [8]. It connects and integrates important infrastructures of the city (including 'city governance, transportation, energy and water, healthcare, information and communication technologies (ICT), education, and public safety') to be more effective and efficient [5]. It is expected to create 'a sustainable urban future'—a smart city which is a system of intelligent systems of infrastructures, as Naphade et al. [5] claim.

Besides, urban innovation is the interaction of innovations in technologies, culture, people, society [12], management, organization, policy [7], and so on. Among such aspects, technologies are one of the most necessary ones for urban innovation [7]. While it is not hard to give examples for such technologies (for instance, ICT as Naphade et al. [5] propose), we do not know the exact structure of the technology landscape and its development over time. What are the technologies that drive urban innovation? In what relationship do they stand to each other? Have there been changes in their influences over time? How can they be analyzed in a system structure?

In our paper, we aim to answer these questions by means of patent analysis. Patent analysis is an accepted instrument to evaluate and monitor technological trajectories in industries [13] which are characterized by a high propensity to patent inventions [14]. In order to process our questions, we apply a system approach, using construction centered on buildings as the central element of urban innovation as Han et al. [8] suggest. Patenting in construction is well reflected in patent systems (with many patent applications in section E in the International Patent Classification (IPC) or the Cooperative Patent Classification (CPC)) [15].

Thus, based on arguments above, this paper learns about urban innovation reflected in construction of buildings by applying analysis of construction patents in different system levels. This research finds out how technologies in urban innovation with the nucleus as the construction of buildings (system), their embedding environment (super-system), their parts (sub-system), and their associated system have developed. This research is implemented in the USA as a leading market of the world. In concrete, the research questions are below:

RQ1: What have the technological drivers of urban innovation reflected in construction patents in the USA been?

RQ2: How has urban innovation reflected in a Technology-DNA (T-DNA) approach grown in the USA over time?

The paper will be presented in some below sections. Section 1 is the introduction of urban innovation and research questions. Section 2 will clarify the term of urban innovation in some researchers' perspectives. Section 3 will analyze some important city infrastructures and the visions of urban innovation. The research methodology will be described in Section 4 and applied to urban innovation in order to create an appropriate data source in Section 5. Based on the data, we develop some findings in Section 6, such as overwhelming influence and growth of the super-system. Finally, some conclusions will be given in Section 7.

2. What Is Urban Innovation?

Urban innovation is the adoption of technologies to improve systems of city infrastructures to be interconnected, intelligent, effective and efficient [5] in combination with smart cooperation of many classes of people [16], the government, smart policies and proper processes [17] in each city's own context [12]. So why is this definition chosen in this paper?

According to Nam and Pardo [7], there are various opinions on how to define urban innovation (Table 1). Some scientists like Washburn et al. [18] focus on technologies and believe that urban innovation is the application of technologies to develop cities' infrastructures and services (such as 'governance, transportation, health care, education, public safety', etc.) to be more efficient and effective. This is similar to the idea of Naphade et al. [5] who also consider technologies, especially ICT, to be very crucial in urban innovation. Technologies are used to control the city—a system of systems of infrastructures and services in a city which are improved through a closed process.

Table 1. Various perspectives on explanation of urban innovation.

Authors	Important Factors of Urban Innovation
Washburn et al. [18]	Technologies
Naphade et al. [5]	Integration of interconnected systems in a city in a closed process
Komninos [16]	Technologies (intellectual properties), people, and knowledge
Han and Hawken [12]	Technologies, businesses, social identity, culture
Meijer and Bolívar [17]	Technologies, politics, processes, smart cooperation, government policies, etc.

Nevertheless, the purpose of urban innovation is to obtain urban sustainability which is based on sustainable economy growth, well-being of social functions, and sustainable environment or energy systems with renewable resources [19]. Thus, Han and Hawken [12] suggest that technologies alone are not sufficient for all economic, social, and environmental fields. Technologies and their business capacities should be put in each city's own cultural and social characteristics as well as governance network in the process of urban innovation to grow their economy and living conditions. In addition, citizens and their cooperation are also necessary in city development. The collaboration of people, along with intellectual properties, a set of knowledge, and the abilities to create new things, is among the most significant factors to make cities smarter [16]. Further, besides technologies and interaction of citizens, Meijer and Bolívar [17] also add some other factors impacting on urban innovation like suitable process approaches for smart cities, political knowledge, and government policies to generate economic and public values.

Therefore, the definition which is mentioned in the beginning of this section is used for this research for two reasons. Firstly, the fact that it sees all infrastructures of cities as systems is suitable to the research method, one of systematic approaches, of this paper (in Section 4). A T-DNA will be formed with four system levels to analyze the development of each system, especially the super-system (in this case city infrastructures). Secondly, interactions of technologies and other social issues are the most adequate viewpoint to develop socio-technical insights into theories and practices for urban innovation [17].

3. Urban Innovation Reflected in City Infrastructures

In order to achieve the visions which are 'smart economy, smart governance, smart mobility, smart environment, smart people, and smart living' [20], urban innovation should heavily focus on city infrastructures and technologies as drivers [7].

3.1. City Infrastructures

City infrastructures are considered as a set of interconnected systems including: 'municipal infrastructures (water and waste management, public safety, street lighting systems); transportation infrastructures (traffic management, public transportation systems); and energy infrastructures (electricity, natural gas supply and district heat systems)' [3]. Besides, Naphade et al. [5] make a similar list: 'transportation, energy and water, other core ICT systems', and add some city services: 'government services, healthcare, and education'. All of them depend on and combine with each other to make cities more effective and efficient. Based on the above two ideas, important city infrastructures are listed in Figure 1.

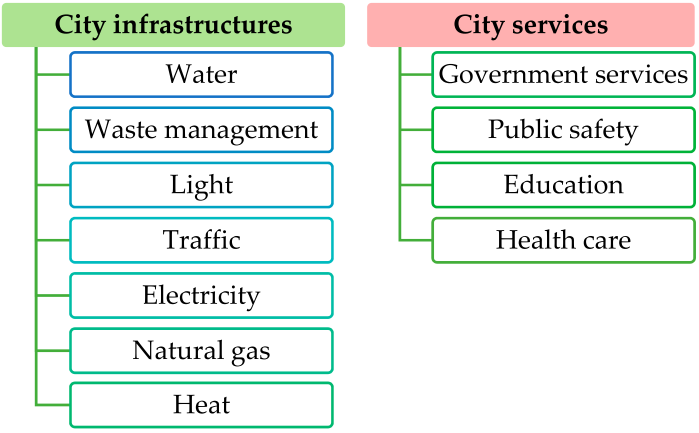

Figure 1. The list of city infrastructures and services.

3.2. Technologies as Drivers for Urban Innovation Visions

Han et al. [8] show the picture of a sustainable urban future in several fields. Firstly, in traffic management system, there should be some crucial changes: transformation of normal cars into hybrid cars, electric cars, or fuel cell cars' to reduce air pollution; improvement of public transportation systems; and additionally, Shahidehpour, Li, and Ganji [3] give a supplementary idea that development of 'vehicular wireless communications including vehicle-to-vehicle and vehicle-to-infrastructure' to help drivers communicate with each other and with traffic controllers to be aware of current traffic situations so that drivers can avoid traffic jams and other traffic problems. Secondly, in buildings, some special devices and materials would be used to decrease the usage of energy, to suit the city's weather and to make buildings more durable. Thirdly, in industries, energy from moving water, wind, the sun, and gas from animal waste (renewable resources) should be used instead of fossil fuels. Last but not least, Han et al. [8] also suggest generating 'green belts' between urban and rural areas to save farming lands and to develop the business model which buys agricultural products in the countryside, processing them to suitable goods, and providing the cities with those goods.

In general, Nam and Pardo [7] claim that all factors such as technologies, citizens, government policies, and the context of each city form the success of urban innovation. In other words, in urban innovation process, with the inspiration of technologies development, city administrators control citizens' activities, share information of the city with people as well as cooperate with technology researchers and practitioners to obtain urban sustainability by making city infrastructures modern [3].

In particular, city administrators arrange all information obtaining from smart sensors and then they manage, optimize and carry out all technological applications in the field of urban innovation to improve city infrastructures and to satisfy citizens (top-down approach). At the same time, citizens also have an active role in identifying features of smart city infrastructures and cooperating with the government to create necessary activities, buildings, equipment, services, and innovations (bottom-up approach) [3]. However, both such sides of this approach should be kept in balance due to the rule, which is called 'ethero-organization'—a significant indicator to make cities more flexible, smart and adaptable to changes [21]. In order to do so, Shahidehpour, Li, and Ganji [3] point out that it is necessary to prepare a holistic urban plan for urban innovation as it will make all city infrastructures more efficient and interdependent to enhance the resilience and efficiency of energy, to reduce pollution, to increase the use of renewable resources, and finally to obtain urban sustainability.

As can be seen easily, the above-mentioned goals cannot be completely achieved without conflicts. For this reason, methods from multi-criteria decision making, such as the analytic hierarchy process (AHP) [22,23] are recommended to be used.

4. Research Methodology

To answer the basic research questions, we suggest the use of a Technology-DNA (T-DNA) approach and the semantic analysis (applying term frequency-inverse document frequency).

Firstly, according to Roepke and Moehrle [24], T-DNA, a technique developed by analogy with the DNA-sequence of creatures, is a new measure to investigate technologies by using patent classifications. For a T-DNA, a system structure needs to be defined, comprising the system itself, its sub-system, its super-system, and its associated system. Moreover, patent activities are also grouped based on those system levels. The study is implemented in the overall picture of related technologies to obtain new understandings and complete perspectives on such technologies' evolution through a series of dominant system level over years and features of each system level. Doing so, the development of a system (in this case urban innovation) can be explained not only by its own movements, but also by influences from other system levels driving the system.

Bellgran and Säfsten [25] propose some perspectives in the system levels, including hierarchical ones: A system is in the relationship of other systems (sub-system or super-system), and each system level is the sub-system of a bigger one. In the method of T-DNA of Roepke and Moehrle [24], the hierarchical relationship of the super-system, the core system, and the sub-system in the four system levels as referred to above is clearly expressed.

- The core system level is seen as the central part of the technology sector which is needed to be analyzed in the research and this system level leads to the occurrence of the others. In our case, we focus on construction, so we interpret buildings as the core system level.
- The sub-system level is composed of many parts which combine with each other to form the core system level. In this paper, the sub-system level is buildings' parts as Bonev, Wörösch, and Hvam [26] propose that the building is the system containing various components such as door, window, foundation, plinth, roof, floor, wall, etc.
- The super-system level includes super-ordinate technologies, and the super-system level operates as the surroundings of the core system one. In buildings, the super-system is the buildings' embedding environments such as energy supply, infrastructure for transportation, or communication technologies.

Technologies in the sub-system, which are parts of the core system, affect the development of technologies in the core system. And in turn, the core system makes technologies in the sub-system changeable by creating changes in the market. In addition, the core system and the super-system have the same relationship.

- The last system level in T-DNA, the associated one, is not in the hierarchy. It contains technologies that may not be components of the technology sector which is being researched but remarkably influence the activities of this sector. Construction machines/tools and materials are elements of the associated system of construction centered on buildings.

Hence, the four system levels in T-DNA are interrelated and affected by the environment, so perhaps the dominant system level is not the same over the years. T-DNA uses the annual number of patents to identify which system level has the highest volume in each year and then to find out T-DNA which is the sequence of dominant system levels. Furthermore, not all patents in each system level are used directly in the development of urban innovation. For instance, patents in electricity and communication may deal with inventions on power supply lines for electrically-propelled vehicles, which could be used in cities, but not exclusively.

In our paper, we apply the method of T-DNA to urban innovation (reflected in construction centered on buildings), using the following four steps: (i) We define the system levels based on CPC, assigning different patent classes to suitable system levels which are coded with letters A, B, C, or D (representing the super-system, the core system, the sub-system, and the associated system, respectively). (ii) We search granted US patents for those classes in the US PatFT applying in the period from 1976 to the end of 2018. Granted patents are accepted by USPTO and they are more reliable than patent applications. Besides, instead of granted date, we use the application date as it is a good factor for the time of invention [27]. (iii) We arrange all patents and assign DNA codes according to years, striving for the most influential system level. (iv) We go in detail in the super-system level and look for different growth rates of its different elements.

Secondly, as Moehrle, Wustmans, and Gerken [28] suggest, the semantic analysis: term frequency-inverse document frequency (tf-idf) is applied in particular to the core system in order to identify important concepts in this system level and then, to explore new fields of buildings related to urban innovation in the four latest years (2011 to 2014) in comparison with the whole time frame (1976 to 2014).

5. Data Source

In order to generate our data set, the method of T-DNA is adopted to patents on construction in the US for creating the four system levels. Then, the disaggregation of the super-system, sub-system and associated system will be demonstrated. Finally, we analyze important terms in the core system by means of the tf-idf measure.

5.1. The Process of T-DNA of Patents on Construction in the US

We apply the T-DNA which was mentioned in Section 4 step by step.

5.1.1. Step 1: Coding Patent Classifications

The classification system of patents that the US is currently using is CPC, so the definitions of each system level in construction will rely on CPC. Due to the large number of keywords connected to buildings, the keyword search method is rejected. In this paper, we suggest reading all sections/classes/subclasses and so on in the CPC scheme and arranging relevant ones in each suitable system level of urban innovation reflected in construction patents. The list of CPC classifications for the four system levels are expressed in Appendix A. And in order to check reliability, this step must be performed in many times.

5.1.2. Step 2: Searching Patents and Organizing Patents to the Four System Levels

In this step, after related patents are searched, all of them must be double-checked to test how precise they are. Finally, "clean" patent counts of each system level will be showed.

- Search patents

All relevant patents to the list of CPC sections/classes/subclasses presented in Appendix A are searched in the data source of US PatFT from 1976 to 2018 based on their application dates. Moreover, the number of granted patents changes day after day, so this research focuses on only patents which have been applied from 1976 to 2018 and issued till 31 December 2018. There are 2,312,097 patents in all system levels of buildings in the US (based on the collected data in January 2019). Additionally, the number of patents in the super-system (code A) has been dominant in the researched period (2,119,968 patents). Besides 9,505 patents; 116,801 patents and 65,823 patents are also found in the core system (code B), the sub-system (code C), and the associated system (code D), respectively.

- Check the super-system

As the super-system level includes a huge number of patents, it is needed to investigate its patents' information to conclude if all CPC sections/classes/subclasses in this system level (Appendix A) are relevant or not. Ten patents in each CPC section/class/subclass of the super-system in Appendix A are selected randomly. Then, if less than five relevant patents in ten selected patents are found in any section/class/subclass, the corresponding one(s) will be removed. As a result, B61B, B64F, B65F, E21, Y02T, Y02W 30/00, and Y02W 90/00, which are highlighted in grey color in Appendix A, should be deleted from the list. The new patent counts of each system level after refinement of the super-system are demonstrated in Table 2. In addition, Figure 2 also shows the development of patent counts in each system level year over year since 1976. As there is the time period between application and grant of a patent, which is normally 3 to 5 years [28], patent counts from 2015 forward are not complete. Hence, next steps will process the data till 2014.

Table 2. The number of patents on each system level in buildings in the US per year (from 1976 to 2018).

Application Year	Super-System	Core System	Sub-System	Associated System	Total
1976	12,399	135	1851	1144	15,529
1977	12,497	135	1882	1189	15,703
1978	12,838	139	1847	1231	16,055
1979	12,801	155	1754	1121	15,831
1980	13,538	104	1769	1128	16,539
1981	12,822	102	1645	1109	15,678
1982	13,229	114	1617	1088	16,048
1983	12,570	92	1625	1003	15,290
1984	13,819	110	1696	1121	16,746
1985	14,929	124	1863	1215	18,131
1986	15,722	155	2089	1273	19,239
1987	16,729	154	2253	1374	20,510
1988	19,227	208	2311	1638	23,384
1989	21,040	190	2581	1681	25,492
1990	21,914	207	2608	1748	26,477
1991	23,367	220	2597	1791	27,975
1992	24,828	199	2436	1605	29,068
1993	25,605	192	2589	1623	30,009
1994	30,861	231	2786	1738	35,616
1995	36,595	225	2993	1881	41,694
1996	41,040	302	3052	1736	46,130
1997	49,460	277	3556	1815	55,108
1998	51,369	278	3363	1706	56,716
1999	56,043	273	3687	1803	61,,806
2000	62,271	284	3731	1923	68,209
2001	67,321	225	3709	2096	73,351
2002	69,167	299	3908	2116	75,490
2003	67,626	247	3767	1760	73,400
2004	69,962	210	3535	1776	75,483
2005	73,208	221	3123	1582	78,134
2006	76,722	194	3125	1662	81,703
2007	79,524	198	3070	1750	84,542
2008	81,140	210	2993	1618	85,961
2009	79,010	212	2925	1805	83,952
2010	84,623	298	3226	1852	89,999
2011	93,527	320	3378	1962	99,187
2012	104,122	355	3626	2016	110,119
2013	108,566	434	4235	2128	115,363
2014	106,121	481	4222	2038	112,862
2015	94,261	449	3641	1509	99,860
2016	67,764	366	2753	990	71,873
2017	31,045	169	1289	435	32,938
2018	2457	12	95	44	2608
Total	**1,983,679**	**9505**	**116,801**	**65,823**	**2,175,808**

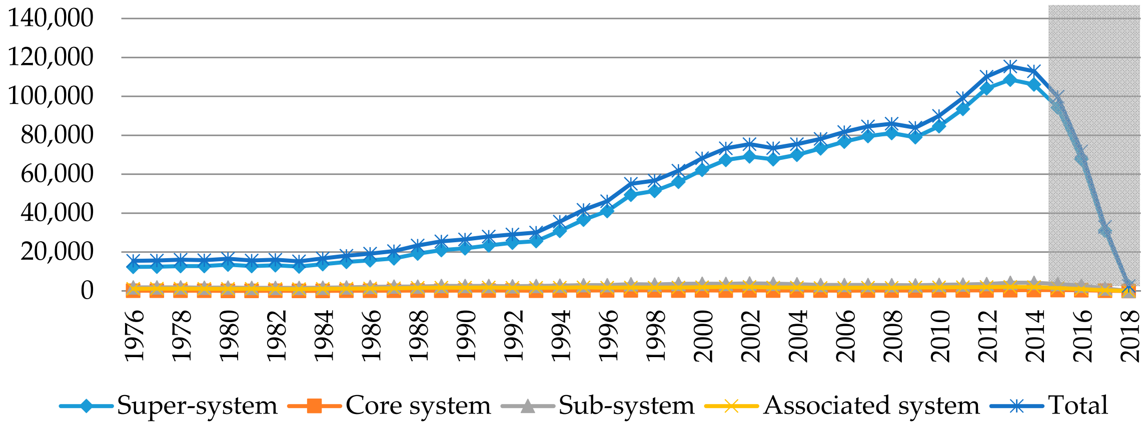

Figure 2. The development of patents activities in construction in the US from 1976 to 2018. (Data is not complete for the years 2015 to 2018 due to reasons in the patenting process. For this reason, we greyed out the data in this period of time.).

- Calculate precision

Last but not least, the precision should be calculated in all patents of the four system levels. Precision is the proportion of the number of relevant documents to the total number of retrieved documents [29].

$$\text{Precision} = N_{\text{retrieved relevant}}/N_{\text{retrieved}} \tag{1}$$

The number of patents is too large for a complete manual evaluation. For this reason, we take samples to check precision. The sample size is decided based on the formula that Israel [30] mentions.

$$n_0 = \frac{Z^2pq}{e^2} \tag{2}$$

n_0 : sample size,
Z : the value correlating to the confidence level required,
p : the predicted proportion showing the attribute of the population
q : 1 − p
e : the expected level of precision

In this case, the sample size is calculated to check again the found data, so it is not a conservative case and the sample size is not needed to be too large. Hence, assume that:

10% of population accepts the practice, so p = 10% and q = 90%

95% confidence level, so Z = 1.96 and e = 10%

Thus:

$$n_0 = \frac{Z^2pq}{e^2} = \frac{1.96^2 \times 10 \times 90}{10^2} = 34.57 \tag{3}$$

Similar calculations lead to similar results for all system levels. We distribute the sample over time. All retrieved patents in each year for each system level will be randomly chosen and checked to look for relevant patent counts and to conclude precision. The precision of the four system levels is quite high (from 54% to 78%), so data in Table 2 after refinement is accepted.

5.1.3. Step 3: Creating T-DNA (Both Relative and Absolute Values)

T-DNA by absolute values is identified by patent counts of each system level in Table 2. This is a way to compare the contributions of each system level to buildings every year. In this case, patent counts in the super-system have always been the dominance in the whole period from 1976 to 2014.

This is easily understood as this system level is related to many fields of technology. Therefore, T-DNA by absolute values of construction in the US from 1976 to 2014 is constant (with code A in all years).

Nevertheless, T-DNA by absolute values could be added by T-DNA by relative values. Relative values show the distribution of the patents in each system level over time. So T-DNA by relative values should be carried out in order to find out how each system level has developed year after year by comparing their relative values among years (the number of patents on each system level in each year divided by the sum of patents in such system level in the whole time). Thus, according to the result of Table 3, T-DNA by relative values of the construction industry in the US from 1976 to 2014 is changing over time. The T-DNA by relative values shows the code which had the dominant contribution in each year from 1976 to 2014.

Table 3. Relative values of patents on each system level and the dominant code in the US per year (from 1976 to 2014).

Application Year	Super-System	Core System	Sub-System	Associated System	The Dominant Code
1976	0.01	0.02	0.02	0.02	D
1977	0.01	0.02	0.02	0.02	D
1978	0.01	0.02	0.02	0.02	D
1979	0.01	0.02	0.02	0.02	B
1980	0.01	0.01	0.02	0.02	D
1981	0.01	0.01	0.02	0.02	D
1982	0.01	0.01	0.01	0.02	D
1983	0.01	0.01	0.01	0.02	D
1984	0.01	0.01	0.02	0.02	D
1985	0.01	0.01	0.02	0.02	D
1986	0.01	0.02	0.02	0.02	D
1987	0.01	0.02	0.02	0.02	D
1988	0.01	0.02	0.02	0.03	D
1989	0.01	0.02	0.02	0.03	D
1990	0.01	0.02	0.02	0.03	D
1991	0.01	0.03	0.02	0.03	D
1992	0.01	0.02	0.02	0.03	D
1993	0.01	0.02	0.02	0.03	D
1994	0.02	0.03	0.03	0.03	D
1995	0.02	0.03	0.03	0.03	D
1996	0.02	0.04	0.03	0.03	B
1997	0.03	0.03	0.03	0.03	C
1998	0.03	0.03	0.03	0.03	B
1999	0.03	0.03	0.03	0.03	C
2000	0.03	0.03	0.03	0.03	A
2001	0.04	0.03	0.03	0.03	A
2002	0.04	0.04	0.04	0.03	A
2003	0.04	0.03	0.03	0.03	A
2004	0.04	0.02	0.03	0.03	A
2005	0.04	0.03	0.03	0.03	A
2006	0.04	0.02	0.03	0.03	A
2007	0.04	0.02	0.03	0.03	A
2008	0.05	0.02	0.03	0.03	A
2009	0.04	0.02	0.03	0.03	A
2010	0.05	0.04	0.03	0.03	A
2011	0.05	0.04	0.03	0.03	A
2012	0.06	0.04	0.03	0.03	A
2013	0.06	0.05	0.04	0.03	A
2014	0.06	0.06	0.04	0.03	A

5.2. Disaggregation

The super-system, the sub-system, and the associated system will be divided into smaller elements to see the development of each field in each system level. The list of CPC sections/classes/subclasses in each system level in Appendix A is classified into some categories (Appendix B). The core system level is not in this disaggregation because it is already on the lowest aggregation level. Later on, T-DNA by absolute and relative values are presented for the super-system to learn about them in detail. The data for the sub-system and the associated system can be found in appendices.

- The super-system

Again, based on Table 4 and Figure 3, it is easy to specify T-DNA by absolute values of the super-system, which is constantly 6 since the number of patents in electricity and communication has always been dominant in this period. And relative values are also presented in Table 4 in brackets. In Figure 3, we use the logarithmic scale for the patent counts because of two reasons. First, it separates better visually between the different technologies and second, it shows the growth rate in a linear way.

- The sub-system

Patent counts of each element of the sub-system are presented in Appendix C and Figure 4. Similarly, T-DNA by absolute values of the sub-system is constantly 3 since the number of patents in door, window, lock, etc. has always been dominant in this period. And the relative values and T-DNA by relative values of this system level, which are also showed in Appendix C (relative values in brackets), is changing over time as well. Again, we use the logarithmic scale in Figure 4 according to the arguments given above.

- The associated system

Appendix D and Figure 5 express the number of patents of this system level in this period. T-DNA by absolute values is constantly 2, and T-DNA by relative values is again changing all the time (Appendix D with relative values in brackets). Again, we use the logarithmic scale in Figure 5 according to the arguments given above.

Table 4. The disaggregation of the super-system in construction in the US from 1976 to 2014 with absolute and relative values of patents on each element per year.

Application Year	Traffic (1)		Water and Hydraulic Engineering (2)		Treatment of Waste (3)		Light (4)		Heat/Cool Air (5)		Electricity and Communication (6)		Climate Change and Environment Protection (7)		Others (8)		Total	The Dominant Code
1976	354 [1]	(0.02) [2]	638	(0.02)	481	(0.02)	228	(0.01)	283	(0.02)	9770	(0.01)	1155	(0.01)	74	(0.02)	12,983	8 [3]
1977	414	(0.02)	619	(0.02)	484	(0.02)	247	(0.01)	333	(0.02)	9705	(0.01)	1301	(0.01)	65	(0.02)	13,168	2
1978	428	(0.02)	562	(0.02)	489	(0.02)	250	(0.01)	342	(0.02)	10,092	(0.01)	1375	(0.01)	83	(0.03)	13,621	8
1979	409	(0.02)	528	(0.02)	474	(0.02)	266	(0.01)	320	(0.02)	10,078	(0.01)	1339	(0.01)	76	(0.02)	13,490	8
1980	401	(0.02)	550	(0.02)	480	(0.02)	260	(0.01)	327	(0.02)	10,822	(0.01)	1381	(0.01)	57	(0.02)	14,278	1
1981	338	(0.02)	449	(0.02)	398	(0.01)	214	(0.01)	328	(0.02)	10,535	(0.01)	1235	(0.01)	73	(0.02)	13,570	8
1982	279	(0.01)	369	(0.01)	350	(0.01)	243	(0.01)	287	(0.02)	11,114	(0.01)	1101	(0.01)	77	(0.02)	13,820	8
1983	270	(0.01)	366	(0.01)	337	(0.01)	224	(0.01)	254	(0.01)	10,693	(0.01)	932	(0.01)	83	(0.03)	13,159	8
1984	350	(0.02)	389	(0.01)	366	(0.01)	330	(0.01)	266	(0.01)	11,601	(0.01)	1111	(0.01)	62	(0.02)	14,475	8
1985	316	(0.02)	441	(0.02)	422	(0.02)	302	(0.01)	300	(0.02)	12,667	(0.01)	1037	(0.01)	66	(0.02)	15,551	8
1986	368	(0.02)	444	(0.02)	435	(0.02)	327	(0.01)	265	(0.01)	13,519	(0.01)	1003	(0.01)	77	(0.02)	16,438	8
1987	398	(0.02)	534	(0.02)	520	(0.02)	369	(0.01)	288	(0.02)	14,320	(0.01)	922	(0.01)	64	(0.02)	17,415	8
1988	524	(0.03)	518	(0.02)	513	(0.02)	461	(0.01)	315	(0.02)	16,639	(0.01)	987	(0.01)	65	(0.02)	20,022	1
1989	476	(0.02)	619	(0.02)	615	(0.02)	537	(0.02)	333	(0.02)	18,159	(0.01)	1096	(0.01)	91	(0.03)	21,926	8
1990	488	(0.02)	632	(0.02)	643	(0.02)	548	(0.02)	348	(0.02)	19,044	(0.01)	1041	(0.01)	67	(0.02)	22,811	1
1991	485	(0.02)	640	(0.02)	692	(0.02)	537	(0.02)	385	(0.02)	20,403	(0.01)	1164	(0.01)	61	(0.02)	24,367	3
1992	498	(0.02)	645	(0.02)	704	(0.03)	547	(0.02)	373	(0.02)	21,716	(0.01)	1358	(0.01)	78	(0.02)	25,919	3
1993	464	(0.02)	609	(0.02)	707	(0.03)	588	(0.02)	415	(0.02)	22,506	(0.01)	1370	(0.01)	54	(0.02)	26,713	3
1994	539	(0.03)	675	(0.02)	813	(0.03)	631	(0.02)	412	(0.02)	27,415	(0.02)	1723	(0.01)	74	(0.02)	32,282	3
1995	632	(0.03)	703	(0.02)	892	(0.03)	695	(0.02)	435	(0.02)	32,837	(0.02)	1819	(0.01)	76	(0.02)	38,089	3
1996	567	(0.03)	730	(0.03)	817	(0.03)	769	(0.02)	473	(0.03)	37,356	(0.02)	1863	(0.01)	79	(0.02)	42,654	3
1997	594	(0.03)	804	(0.03)	853	(0.03)	826	(0.02)	499	(0.03)	45,601	(0.03)	2021	(0.02)	97	(0.03)	51,295	8
1998	585	(0.03)	744	(0.03)	826	(0.03)	832	(0.02)	496	(0.03)	47,789	(0.03)	2047	(0.02)	70	(0.02)	53,389	3
1999	651	(0.03)	813	(0.03)	913	(0.03)	914	(0.03)	478	(0.03)	52,184	(0.03)	2288	(0.02)	91	(0.03)	58,332	3
2000	627	(0.03)	845	(0.03)	966	(0.03)	1073	(0.03)	490	(0.03)	58,338	(0.04)	2565	(0.02)	81	(0.03)	64,985	6
2001	621	(0.03)	794	(0.03)	947	(0.03)	1107	(0.03)	589	(0.03)	63,769	(0.04)	3312	(0.03)	171	(0.05)	71,310	8
2002	675	(0.03)	854	(0.03)	963	(0.03)	1185	(0.03)	561	(0.03)	64,421	(0.04)	3463	(0.03)	75	(0.02)	72,197	6
2003	572	(0.03)	846	(0.03)	815	(0.03)	1227	(0.03)	598	(0.03)	63,202	(0.04)	3427	(0.03)	73	(0.02)	70,760	6
2004	568	(0.03)	776	(0.03)	816	(0.03)	1139	(0.03)	580	(0.03)	65,601	(0.04)	3838	(0.03)	56	(0.02)	73,374	6
2005	577	(0.03)	787	(0.03)	862	(0.03)	1208	(0.03)	538	(0.03)	68,876	(0.04)	4264	(0.03)	72	(0.02)	77,184	6
2006	548	(0.03)	789	(0.03)	827	(0.03)	1254	(0.04)	488	(0.03)	72,405	(0.04)	4731	(0.04)	53	(0.02)	81,095	6
2007	541	(0.03)	843	(0.03)	863	(0.03)	1338	(0.04)	518	(0.03)	74,955	(0.05)	5705	(0.04)	79	(0.02)	84,842	6
2008	586	(0.03)	810	(0.03)	857	(0.03)	1566	(0.04)	507	(0.03)	76,127	(0.05)	6719	(0.05)	67	(0.02)	87,239	7
2009	485	(0.02)	823	(0.03)	818	(0.03)	1646	(0.05)	561	(0.03)	73,813	(0.04)	7736	(0.06)	87	(0.03)	85,969	7
2010	636	(0.03)	963	(0.03)	1000	(0.04)	1816	(0.05)	681	(0.04)	78,732	(0.05)	9374	(0.07)	92	(0.03)	93,294	7
2011	694	(0.03)	1082	(0.04)	983	(0.03)	2164	(0.06)	727	(0.04)	87,463	(0.05)	10,732	(0.08)	121	(0.04)	103,966	7
2012	810	(0.04)	1262	(0.04)	1068	(0.04)	2390	(0.07)	865	(0.05)	97,784	(0.06)	11,574	(0.09)	116	(0.04)	115,869	7
2013	844	(0.04)	1276	(0.05)	1105	(0.04)	2797	(0.08)	907	(0.05)	102,383	(0.06)	11,426	(0.09)	130	(0.04)	120,868	7
2014	897	(0.04)	1377	(0.05)	993	(0.04)	2546	(0.07)	945	(0.05)	100,434	(0.06)	9621	(0.07)	128	(0.04)	116,941	7
Total	**20,509**		**28,148**		**28,107**		**35,601**		**18,110**		**1,644,868**		**131,156**		**3,161**		**1,909,660**	

[1] The absolute values are in the first column of each element. [2] The relative values are put in the other with brackets. [3] The dominant code belongs to relative values.

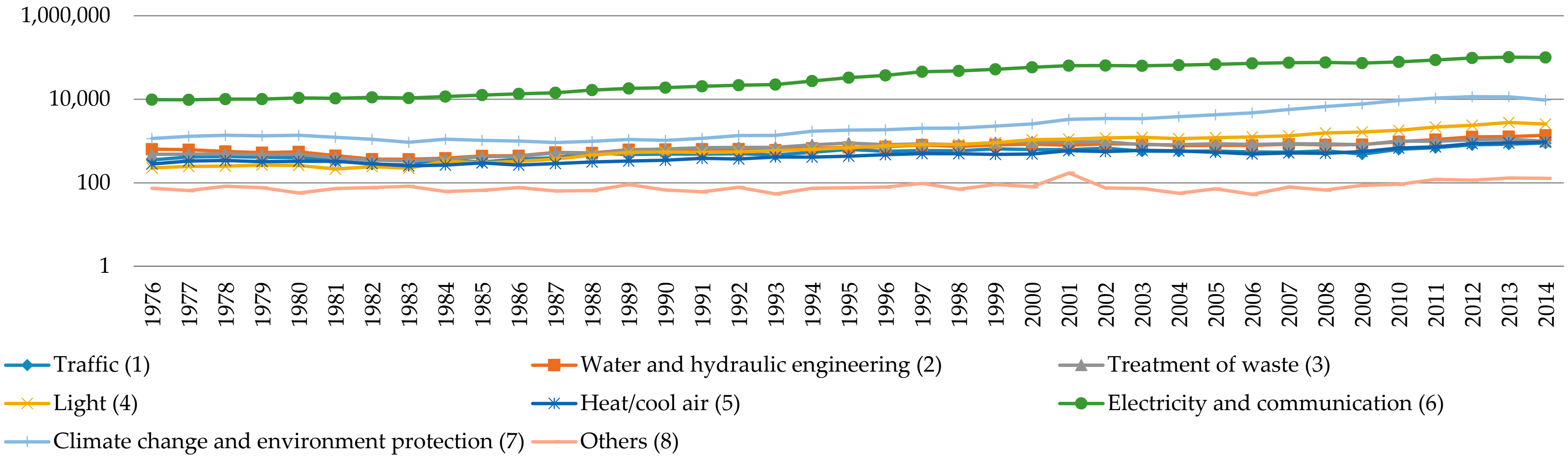

Figure 3. The development of patents activities in each element of the super-system in construction in the US from 1976 to 2014.

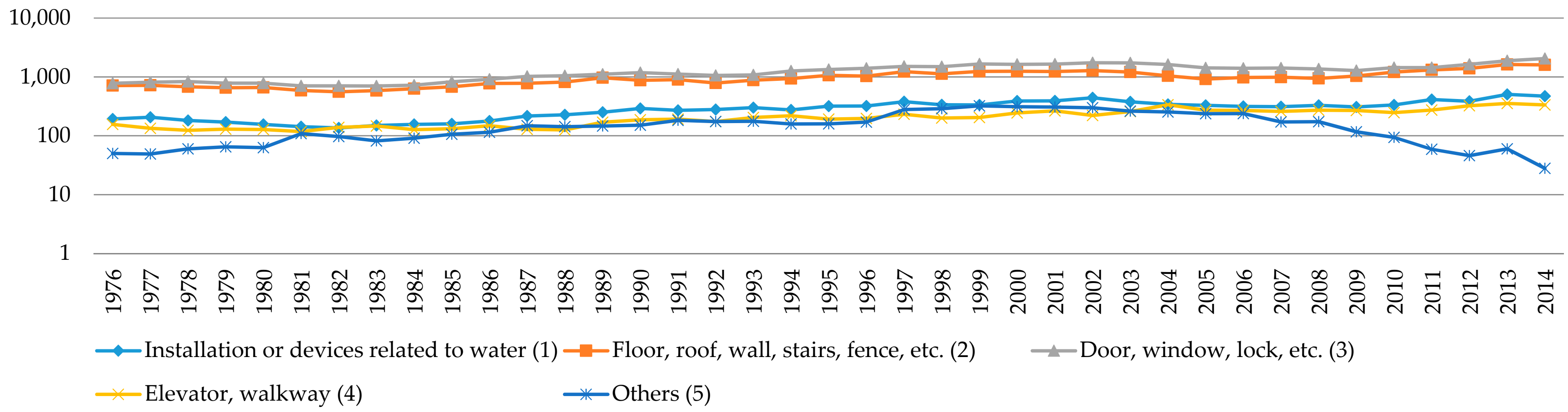

Figure 4. The development of patents activities in each element of the sub-system in construction from 1976 to 2014.

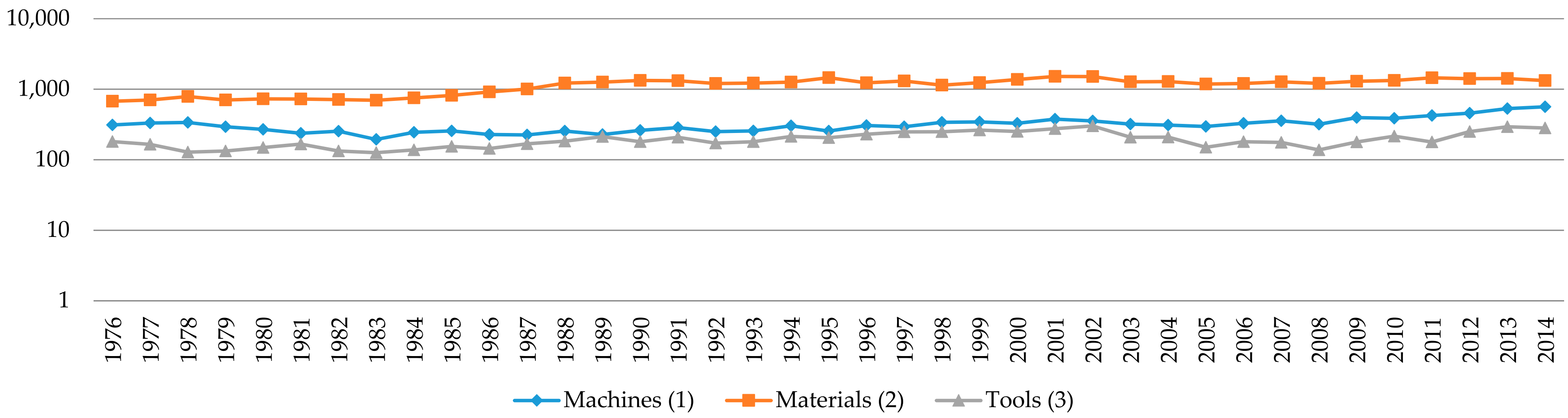

Figure 5. The development of patents activities in each element of the associated system in construction in the US from 1976 to 2014.

5.3. Important Terms in the Core System

According to Moehrle, Wustmans, and Gerken [28], we take out bi-grams (two-word concepts) in the window size of four (combining each word with another one in each four adjacent words in succession) from the full text of each patent of the core system in the period of 1976 to 2014 and from 2011 to 2014. This is implemented after cleaning patent data by removing punctuation marks and stop words as well as transforming all words into their basic forms. After that, tf-idf for each discovered bi-gram is calculated. This is a measure to emphasize concepts which usually appear in a small number of patents but are not common in the whole set of patents. The higher this measure is, the more interesting such concepts are.

$$\mathrm{tf-idf_{ij}} = \mathrm{tf_{ij}} \times \mathrm{idf_{ij}} = \mathrm{tf_{ij}} \times \log\left(\frac{\mathrm{S_j}}{\mathrm{df_{ij}}}\right) \quad (4)$$

$\mathrm{tf_{ij}}$: term frequency of the concept i in the year j;
$\mathrm{idf_{ij}}$: inverse document frequency of the concept i in the year j;
$\mathrm{S_{j:}}$ the number of patents in the year j;
$\mathrm{df_{ij}}$: document frequency of the concept i in the year j.

Table 5 shows 20 concepts of each period (from 2011 to 2014 and from 1976 to 2014) with the highest tf-idf.

Table 5. Important bi-grams of patents in the core system in the periods of 1976 to 2014 and 2011 to 2014.

No. \ Periods	1976 to 2014	2011 to 2014
1	side wall	side wall
2	panel wall	panel wall
3	panel side	panel panel
4	panel panel	frame frame
5	lower upper	panel side
6	portion portion	base plate
7	wall wall	panel roof
8	panel roof	**panel solar**
9	side side	portion portion
10	frame frame	side side
11	edge panel	lower upper
12	portion upper	floor panel
13	edge side	wall wall
14	building structure	assembly wall
15	floor panel	**turbine wind**
16	lower portion	protective shelter
17	outer surface	plate plate
18	pole pole	assembly panel
19	base plate	frame structure
20	portion side	panel plurality

6. Results and Discussion

The data source, which was presented in tables and figures above, suggests some findings.

Firstly, Table 2 and Figure 2 demonstrate that the number of patents of all system levels significantly increased from 1976 to 2014, especially from the end of the 1990s and the beginning of the 2000s forward. Applying the formula of Paquett [31], the compound growth rate of patents in all system levels is:

$$r = \sqrt[n]{\frac{E}{B}} - 1 = \sqrt[38]{\frac{112,862}{15,529}} - 1 = 5.36\%$$

(r: compound growth rate (CGR) of patents;
E: patent count of the end year–2014;
B: patent count of the beginning year–1976;
n: the number of years in the period)

It is really obvious that the super-system (city infrastructures) had the huge contribution to this whole picture due to its large CGR: 5.81% (calculated by the same formula), meanwhile the CGRs of the core system, the sub-system and the associated system are 3.40%; 2.19% and 1.53%, respectively. Besides, the CGR of the super-system is even greater than that of the total US patent count from 1976 to 2014 ($\sqrt[38]{\frac{250,412}{65,795}} - 1 = 3.58\%$).

Secondly, in addition, Table 4, disaggregation of the super-system, shows some driving forces of this system level which have the greatest patent count among all elements: light, electricity and communication, and climate change and environment protection. The CGRs of these elements are also really high: 6.56%; 6.32%; and 5.74%; respectively.

Thirdly, as mentioned above, Table 2 and Figure 2 express the dominant code of the four system levels in the whole time of the period was A (the super-system), which means that besides its huge growth rate, the super-system also has the largest number of patents every year.

Fourthly, relative values of all system levels (Table 3) manifest how each system level developed over years. While T-DNA by relative values was represented by mostly code D (the associated system) from 1976 to 1995 (the first stage), the period from 1996 to 1999 (the second stage) is the transformation (which looks random in each year) and from 2000 forward (the third stage), code A (the super-system) was the dominance. The contributive volume (relative value) of the associated system of each year in the first stage is about 0.02 or 0.03 and these were also the high number in comparison with the other system levels in this stage. However, in the next stages, the volume of the associated one has not changed much. On the contrary, the super-system had the very low contributive amount of 0.01 in the first stage, but this volume considerably raised to 0.03, 0.04, 0.05, or even 0.06 in the third stage. This presents that there were very big changes in the super-system from 2000 forwards, which is explained by the fifth finding.

Fifthly, in the disaggregation of the super-system, Table 4 expresses each element's contributive volume of each year in its total patent count from 1976 to 2014 (numbers in brackets). Especially, from 2000 forward, electricity and communication, and climate change and environment protection have always been in T-DNA by relative values of elements in the super-system since the contributive volume of these two elements considerably increased and had a large change in this stage, as Han et al. [8] propose that environment, electricity and communications have been significant issues recently. This made the super-system dramatically increase in its patent count and its relative values in comparison to other system levels from 2000. Furthermore, patent counts of electricity and communication, and climate change and environment protection in 2014 increased 10 times compared to 1976 and their growth factor was the largest compared to other components (2 or 3 times).

Sixthly, Table 4 and Figure 3 also show the dominant absolute values of the super-system belonged to electricity and communication. This element always had the greatest number of patents among several elements of this system level, presenting its large contribution to the super-system over years.

Seventhly, Appendix C—Figure 4, and Appendix D—Figure 5 show T-DNA by absolute values of the sub-system and associated system. The dominant code of the former has always been code 3 (door, window, lock, etc.), and code 2 (materials) has been dominant in the latter. Moreover, all elements of the sub-system and the associated system had the low growth factor of 2–2.6 and 1.5–2, respectively. Furthermore, Appendices C and D also present T-DNA by relative values of these two system levels (in brackets) but the finding does not show any special results as the dominant codes look like random over years in both system levels.

Eighthly, in Table 5, in both periods (in 2011 to 2014 and the whole time from 1976 to 2014), by applying tf-idf to the core system, several interesting concepts related to buildings and their parts such as 'building structure', 'protective shelter', 'side wall', 'panel roof', 'floor panel', 'pole pole', 'lower portion', etc., are found. This fact is a predicted result as those concepts are definitely used to describe buildings—the core system. However, two new concepts which have emerged in the latest four years from 2011 to 2014 are 'panel solar' and 'turbine wind'. These concepts include solar and wind energies—the important parts of city infrastructures in urban innovation, which means that technologies in the core system have started to develop in the direction of urban innovation visions.

7. Conclusions

Urban innovation focuses on improvement of city infrastructures in proper processes to achieve urban innovation visions. One major influence of urban innovation is the sphere of technology and we aim to understand in detail which technologies are driving. For this purpose, we investigate urban innovation in a T-DNA approach. We find that the core system of buildings, the sub-system regarding parts of buildings, and the associated system have only limited impact on the development of urban innovation. Still they all grew with more or less the same rate as the total US patents. It is the super-system which drives dominantly. In particular, technologies in electricity and communication as well as technologies related to climate change and environment protection have had a major increase in terms of granted patent count between 1976 and 2014 by factor ten (compared to other technologies with a factor around two or three). Especially, from 2000 forward, the super-system has had big increases in such two technologies.

Theoretical implications: Our study provides a systematic classification of technologies regarding urban innovation in the framework of the T-DNA. It shows the development of technological landscape which can be used in other researches as well. It provides a better understanding in particular how the infrastructures are developing and driving the other parts of urban innovation. The modeling of T-DNA may also be interesting for other research fields, in particular if they are based on some kinds of infrastructures.

Practical implications: Our research may help managers in companies as well as politicians in urban areas. Managers can analyze the drivers of urban innovation based on the T-DNA structure, use it as technology monitoring system, analyze the implications for technologies forecasting, and integrate major drivers in their business. Politicians can check if their decisions regarding urban innovation take account of all relevant elements of the four system levels. According to these assessments, they can adapt to the new environmental situations and technological opportunities. The super-system, especially the technologies in electricity and communication as well as climate change and environment protection have been identified as important drivers for urban innovation, so planners should consider their impact more comprehensively in the future. However, specific development in other system levels should be paid attention as well besides infrastructures and services in the super-system since urban innovation visions, which are mentioned in the theory, include the development of more durable buildings and natural materials suitable to each city's weather.

Limitations: As usual, our approach is limited in several ways: (i) We use patent classifications to delineate relevant technologies. Although we did an extensive refinement, some patents in particular in the classes of super, sub and associated system may only stay in loose relationship to urban innovation. (ii) We only looked at the technological drivers of urban innovation. Urban innovation is based on not only technologies but also a complex cooperation of central actors, such as the citizens, the government, the planners, the companies, and others, which may influence the technological development and in particular the acceptance of specific technologies as well. (iii) Our data was based on the USPTO. Although the US market for urban innovation is large, pioneering cities may be found in other countries as well, such as China, Singapore, or United Arab Emirates. Hence, regional characteristics may influence patenting and in consequence our results. (iv) In our analysis, we do not consider the inner movement of technologies, e.g., in convergence processes. For this reason, we cannot answer which technologies boundaries are blurring.

Further research: Our further research is connected to overcome the limitations: (i) Better delineations of relevant technologies could be developed based on co-classification or co-citation analyses. (ii) The system approach, which constitutes the T-DNA, could be enlarged to different actors who cooperate with each other for urban innovation. For instance, Twitter analyses of citizens could show how people think about a technology and in which way they are going to use it. (iii) Our classification is based upon the Cooperative Patent Classification (CPC), which is a follow-up of the International Patent Classification (IPC). Other researchers could rely on this classification in other countries, in which one of these patent classifications (CPC or IPC) is used in their patent systems. For instance, they might compare the results from the USA with results from other developed countries, such as Canada, France, or the UK, and from emerging countries, such as China, India, or Brazil, to find out similarities and differences in the development of urban innovation. Our T-DNA classification can be used to select two cities in different countries in order to analyze regional characteristics. Our results can lead researchers to a focus on such drivers of urban innovation that had major influence in the past and still have major influence currently in the present and in the future because many patents are still valid and alive. (iv) Further research could focus on the movement between technologies, for instance based on a co-classification, a co-citation, or a semantic patent analysis.

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Appendix A

Table A1. CPC Patent Classifications of the Four System Levels in Building Construction (from CPC Scheme [32]).

System Level/Symbol		Sections/Classes Title
Core System (Code B)		
E04H (except E04H 4/00, 7/00 and 17/00) [1]	1/00	Buildings or groups of buildings for dwelling or office purposes; General layout, e.g., modular co-ordination, staggered storeys
	3/00	Buildings or groups of buildings for public or similar purposes; Institutions, e.g., infirmaries, prisons
	5/00	Buildings or groups of buildings for industrial or agricultural purposes
	6/00	Buildings for parking cars, rolling-stock, aircraft, vessels, or like vehicles, e.g., garages
	9/00	Buildings, groups of buildings, or shelters, adapted to withstand or provide protection against, abnormal external influences, e.g., war-like action, earthquake, extreme climate
	12/00	Towers; Masts or poles; Chimney stacks; Water-towers; Methods of erecting such structures
	13/00	Monuments; Tombs; Burial vaults; Columbaria
	14/00	Buildings for combinations of different purposes not covered by any single one of main groups E04H 1/00-E04H 13/00 of this subclass, e.g., for double purpose
	15/00	Tents or canopies, in general

Table A1. *Cont.*

System Level/Symbol		Sections/Classes Title
Sub-System (Code C)		
E03C		Domestic plumbing installations for fresh water or waste water
E03D		Water-closets or urinals with flushing devices; flushing valves therefor
E04B		General building constructions; walls, e.g., partitions; roofs; floors; ceilings; insulation or other protection of buildings
E04C		Structural elements; building materials
E04D		Roof coverings; sky-lights; gutters; roof-working tools
E04F		Finishing work on buildings, e.g., stairs, floors
E04H	4/00	Swimming or splash baths or pools
	17/00	Fencing, e.g., fences, enclosures, corrals
E05		Locks; keys; window or door fittings; safes
E06		Doors, windows, shutters, or roller blinds, in general; ladders
B66B		Elevators; escalators or moving walkways
B66D		Capstans; winches; tackles, e.g., pulley blocks; hoists
Y10S	4/00	Baths, closets, sinks, and spittoons
	52/03	Static structures, e.g., buildings: Trailer or mobile home skirt
	52/16	Static structures, e.g., buildings: Roofing with pressure sensitive adhesive, e.g., shingle
	52/17	Static structures, e.g., buildings: with transparent walls or roof, e.g., sunroom
	174/00	Electricity: conductors and insulators
	256/00	Fences
	439/00	Electrical connectors
Super-System (Code A)		
E01		Construction of roads, railways, or bridges
E02 (except E02B 11/00, 13/00, 15/00 and 17/00) [2]		Hydraulic engineering; foundations; soil-shifting
E03B		Installations or methods for obtaining, collecting, or distributing water
E03F		Sewers; cesspools
E21		Earth drilling; mining
B60M		Power supply lines, or devices along rails, for electrically-propelled vehicles
B61B		Railway systems; equipment therefor not otherwise provided for
B61L		Guiding railway traffic; ensuring the safety of railway traffic
B64F		Ground or aircraft-carrier-deck installations specially adapted for use in connection with aircraft; designing, manufacturing, assembling, cleaning, maintaining or repairing aircraft, not otherwise provided for; handling, transporting, testing or inspecting aircraft components, not otherwise provided for
B65F		Gathering or removal of domestic or like refuse
C02		Treatment of water, waste water, sewage, or sludge
F21		Lighting
F24D		Domestic- or space-heating systems, e.g., central heating systems; domestic hot-water supply systems; elements or components therefor
F24F		Air-conditioning; air-humidification; ventilation; use of air currents for screening
H		Electricity
Y02A	20/00	Water conservation; Efficient water supply; Efficient water use
	30/00	Adapting or protecting infrastructure or their operation
Y02B		Climate change mitigation technologies related to buildings, e.g., housing, house appliances or related end-user applications
Y02D		Climate change mitigation technologies in information and communication technologies [ICT], i.e., information and communication technologies aiming at the reduction of thir own energy use

Table A1. *Cont.*

System Level/Symbol		Sections/Classes Title
Y02E		Reduction of greenhouse gas [GHG] emissions, related to energy generation, transmission or distribution
Y02T		Climate change mitigation technologies related to transportation
Y02W	10/00	Technologies for wastewater treatment
	30/00	Technologies for solid waste management
	90/00	Enabling technologies or technologies with a potential or indirect contribution to greenhouse gas [GHG] emissions mitigation
Y04		Information or communication technologies having an impact on other technology areas
Y10S	48/00	Gas: heating and illuminating
	132/902	Toilet: Liquid treating forms and mandrels
	200/00	Electricity: circuit makers and breakers
	237/00	Heating systems
	238/00	Railways: surface track
	246/00	Railway switches and signals
	307/00	Electrical transmission or interconnection systems
	322/00	Electricity: single generator systems
	323/00	Electricity: power supply or regulation systems
	343/00	Communications: radio wave antennas
	348/00	Television
	362/00	Illumination
	367/00	Communications, electrical: acoustic wave systems and devices
	370/00	Multiplex communications
	372/00	Coherent light generators
	379/00	Telephonic communications
	388/00	Electricity: motor control systems
	474/00	Endless belt power transmission systems or components
Y10T 307/00		Electrical transmission or interconnection systems
Associated System (Code D)		
E04G		Scaffolding; forms; shuttering; building implements or other building aids, or their use; handling building materials on the site; repairing, breaking-up or other work on existing buildings
E04H 7/00		Construction or assembling of bulk storage containers employing civil engineering techniques in situ or off the site
B28		Working cement, clay, or stone
B66C		Cranes; load-engaging elements or devices for cranes, capstans, winches, or tackles
B66F		Hoisting, lifting, hauling, or pushing, not otherwise provided for, e.g., devices which apply a lifting or pushing force directly to the surface of a load
C04		Cements; concrete; artificial stone; ceramics; refractories
Y10S	52/00 (except Y10S 52/03, 52/16 and 52/17) [3]	Static structures, e.g., buildings
	187/90	Temporary construction elevator for building

Table A1. *Cont.*

System Level/Symbol	Sections/Classes Title
Y02P 40/00	Technologies relating to the processing of minerals

[1] "E04H 4/00: Swimming or splash baths or pools" and "E04H 17/00: Fencing, e.g., fences, enclosures, corrals" include parts of buildings, so they must be in the sub-system. "E04H 7/00: Construction or assembling of bulk storage containers employing civil engineering techniques in situ or off the site" is a tool which is created in construction sites to contain some kinds of fluids, gases or materials for building processes, so it must be in the associated system. [2] "E02B 11/00: Drainage of soil, e.g., for agricultural purposes"; "E02B 13/00: Irrigation ditches, i.e., gravity flow, open channel water distribution systems"; "E02B 15/00: Cleaning or keeping clear the surface of open water; Apparatus therefor"; and "E02B 17/00: Artificial islands mounted on piles or like supports, e.g., platforms on raisable legs; Construction methods therefor" are not related to buildings and its super-system. [3] "Y10S 52/03: Static structures, e.g., buildings: Trailer or mobile home skirt"; "Y10S 52/16: Static structures, e.g., buildings: Roofing with pressure sensitive adhesive, e.g., shingle"; and "Y10S 52/17: Static structures, e.g., buildings: with transparent walls or roof, e.g., sunroom" include parts of buildings, so they must be in the sub-system. All CPC sections/classes/subclasses which are highlighted in grey should be deleted after the refinement of the super-system.).

Appendix B

Table A2. The Disaggregation of the Super-System, the Sub-System and the Associated System of Patents on Buildings in the US.

Categories	Symbol		Sections/Classes Title
Super-System			
Traffic	E01		Construction of roads, railways, or bridges
	E02B 5/00		Artificial water canals
	E02C		Ship-lifting devices or mechanisms
	B60M		Power supply lines, or devices along rails, for electrically-propelled vehicles
	B61L		Guiding railway traffic; ensuring the safety of railway traffic
	Y10S	238/00	Railways: surface track
		246/00	Railway switches and signals
Water and hydraulic engineering	E02B	1/00	Equipment or apparatus for, or methods of, general hydraulic engineering
		3/00	Engineering work in connection with control or use of streams, rivers, coasts, or other marine sites (barrages or weirs E02B 7/00); Sealings or joints for engineering work in general
		7/00	Barrages or weirs; Layout, construction, methods of, or devices for, making same
		8/00	Details of barrages or weirs
		9/00	Water-power plants; Layout, construction or equipment, methods of, or apparatus for, making same
		2201/00	Devices, constructional details or methods of hydraulic engineering not otherwise provided for
	E02D		Foundations; excavations; embankments; Underground or underwater structures
	E02F		Dredging; soil-shifting
	E03B		Installations or methods for obtaining, collecting, or distributing water
	E03F		Sewers; cesspools
	Y02A 20/00		Water conservation; Efficient water supply; Efficient water use
Treatment of waste	C02		Treatment of water, waste water, sewage, or sludge
	Y10S 132/902		Toilet: Liquid treating forms and mandrels
	Y02W 10/00		Technologies for wastewater treatment

Table A2. *Cont.*

Categories	Symbol		Sections/Classes Title
Light	F21		Lighting
	Y10S	362/00	Illumination
		372/00	Coherent light generators
Heat/cool air	F24D		Domestic- or space-heating systems, e.g., central heating systems; domestic hot-water supply systems; elements or components therefor
	F24F		Air-conditioning; air-humidification; ventilation; use of air currents for screening
	Y10S 237/00		Heating systems
Electricity and communication	H		Electricity
	Y04		Information or communication technologies having an impact on other technology areas
	Y10T 307/00		Electrical transmission or interconnection systems
	Y10S	200/00	Electricity: circuit makers and breakers
		307/00	Electrical transmission or interconnection systems
		322/00	Electricity: single generator systems
		323/00	Electricity: power supply or regulation systems
		343/00	Communications: radio wave antennas
		348/00	Television
		367/00	Communications, electrical: acoustic wave systems and devices
		370/00	Multiplex communications
		379/00	Telephonic communications
		388/00	Electricity: motor control systems
		474/00	Endless belt power transmission systems or components
Climate change and environment protection	Y02B		Climate change mitigation technologies related to buildings, e.g., housing, house appliances or related end-user applications
	Y02D		Climate change mitigation technologies in information and communication technologies [ICT], i.e., information and communication technologies aiming at the reduction of thir own energy use
	Y02E		Reduction of greenhouse gas [GHG] emissions, related to energy generation, transmission or distribution
Others	Y02A 30/00		Adapting or protecting infrastructure or their operation
	Y10S 48/00		Gas: heating and illuminating
Sub-System			
Installation or devices related to water	E03C		Domestic plumbing installations for fresh water or waste water
	E03D		Water-closets or urinals with flushing devices; flushing valves therefor
	E04H 4/00		Swimming or splash baths or pools
	Y10S 4/00		Baths, closets, sinks, and spittoons
Floor, roof, wall, stairs, fence, etc.	E04B		General building constructions; walls, e.g., partitions; roofs; floors; ceilings; insulation or other protection of buildings
	E04C		Structural elements; building materials
	E04D		Roof coverings; sky-lights; gutters; roof-working tools
	E04F		Finishing work on buildings, e.g., stairs, floors
	E04H 17/00		Fencing, e.g., fences, enclosures, corrals

Table A2. *Cont.*

Categories	Symbol		Sections/Classes Title
Floor, roof, wall, stairs, fence, etc.	Y10S	52/03	Static structures, e.g., buildings: Trailer or mobile home skirt
		52/16	Static structures, e.g., buildings: Roofing with pressure sensitive adhesive, e.g., shingle
		52/17	Static structures, e.g., buildings: with transparent walls or roof, e.g., sunroom
		256/00	Fences
Door, window, lock, etc.	E05		Locks; keys; window or door fittings; safes
	E06		Doors, windows, shutters, or roller blinds, in general; ladders
Elevator, walkway	B66B		Elevators; escalators or moving walkways
	B66D		Capstans; winches; tackles, e.g., pulley blocks; hoists
Others	Y10S	174/00	Electricity: conductors and insulators
		439/00	Electrical connectors
Associated System			
Tools	E04G		Scaffolding; forms; shuttering; building implements or other building aids, or their use; handling building materials on the site; repairing, breaking-up or other work on existing buildings
	E04H 7/00		Construction or assembling of bulk storage containers employing civil engineering techniques in situ or off the site
	Y10S	52/01	Hand tools for assembling building components
		52/02	Masonry lattice or openwork
		52/05	Designed for thermal distortion
		52/06	Toothed connecting means
		52/08	Imitation beams
		52/09	Structure including reclaimed component, e.g., trash
		52/10	Polyhedron
		52/11	Mobile-structure stabilizing anchor
		52/12	Temporary protective expedient
		52/13	Hook and loop type fastener
		52/14	Shelter shaped to article configuration
		52/15	Seal for corrugated sheets
Materials	B28		Working cement, clay, or stone
	C04		Cements; concrete; artificial stone; ceramics; refractories
	Y10S	52/07	Synthetic building materials, reinforcements and equivalents
		52/90	Hazardous material permeation prevention, e.g., radon
	Y02P 40/00		Technologies relating to the processing of minerals
Machines	B66C		Cranes; load-engaging elements or devices for cranes, capstans, winches, or tackles
	B66F		Hoisting, lifting, hauling, or pushing, not otherwise provided for, e.g., devices which apply a lifting or pushing force directly to the surface of a load
	Y10S 52/04		Magnetic connecting means for building components

Appendix C

Table A3. The Disaggregation of the Sub-System in Construction in the US from 1976 to 2014 with Absolute and Relative Values of Patents on Each Element Per Year.

Year	Installation or Devices Related to Water (1)		Floor, Roof, Wall, Stairs, Fence, etc. (2)		Door, Window, Lock, etc. (3)		Elevator, Walkway (4)		Others (5)		Total	The Dominant Code
1976	193 [1]	(0.02) [2]	713	(0.02)	778	(0.02)	156	(0.02)	50	(0.01)	1890	4 [3]
1977	207	(0.02)	720	(0.02)	813	(0.02)	134	(0.02)	49	(0.01)	1923	2
1978	182	(0.02)	681	(0.02)	835	(0.02)	124	(0.02)	60	(0.01)	1882	2
1979	171	(0.02)	656	(0.02)	786	(0.02)	130	(0.02)	65	(0.01)	1808	2
1980	156	(0.01)	663	(0.02)	785	(0.02)	128	(0.02)	63	(0.01)	1795	2
1981	143	(0.01)	590	(0.02)	706	(0.01)	118	(0.01)	109	(0.02)	1666	5
1982	136	(0.01)	559	(0.01)	707	(0.01)	139	(0.02)	97	(0.02)	1638	4
1983	150	(0.01)	585	(0.02)	702	(0.01)	147	(0.02)	82	(0.01)	1666	4
1984	156	(0.01)	631	(0.02)	726	(0.01)	127	(0.02)	91	(0.02)	1731	2
1985	160	(0.01)	680	(0.02)	826	(0.02)	132	(0.02)	106	(0.02)	1904	2
1986	178	(0.02)	776	(0.02)	916	(0.02)	148	(0.02)	115	(0.02)	2133	2
1987	217	(0.02)	781	(0.02)	1020	(0.02)	129	(0.02)	148	(0.02)	2295	5
1988	227	(0.02)	816	(0.02)	1047	(0.02)	126	(0.02)	143	(0.02)	2359	5
1989	251	(0.02)	970	(0.03)	1109	(0.02)	170	(0.02)	147	(0.02)	2647	2
1990	292	(0.03)	876	(0.02)	1183	(0.02)	187	(0.02)	151	(0.02)	2689	1
1991	271	(0.02)	900	(0.02)	1117	(0.02)	192	(0.02)	183	(0.03)	2663	5
1992	279	(0.02)	790	(0.02)	1062	(0.02)	175	(0.02)	175	(0.03)	2481	5
1993	301	(0.03)	879	(0.02)	1083	(0.02)	205	(0.03)	176	(0.03)	2644	5
1994	275	(0.02)	941	(0.02)	1263	(0.03)	219	(0.03)	159	(0.03)	2857	4
1995	319	(0.03)	1.065	(0.03)	1335	(0.03)	192	(0.02)	160	(0.03)	3071	1
1996	320	(0.03)	1.032	(0.03)	1403	(0.03)	197	(0.02)	171	(0.03)	3123	3
1997	380	(0.03)	1.229	(0.03)	1508	(0.03)	232	(0.03)	279	(0.05)	3628	5
1998	336	(0.03)	1.128	(0.03)	1497	(0.03)	200	(0.02)	289	(0.05)	3450	5
1999	334	(0.03)	1.245	(0.03)	1662	(0.03)	205	(0.03)	323	(0.05)	3769	5
2000	391	(0.03)	1.247	(0.03)	1634	(0.03)	245	(0.03)	313	(0.05)	3830	5
2001	392	(0.03)	1.239	(0.03)	1657	(0.03)	265	(0.03)	308	(0.05)	3861	5
2002	442	(0.04)	1.283	(0.03)	1744	(0.04)	221	(0.03)	299	(0.05)	3989	5
2003	377	(0.03)	1.212	(0.03)	1735	(0.04)	258	(0.03)	263	(0.04)	3845	5
2004	342	(0.03)	1.046	(0.03)	1630	(0.03)	337	(0.04)	254	(0.04)	3609	5
2005	329	(0.03)	918	(0.02)	1428	(0.03)	272	(0.03)	237	(0.04)	3184	5
2006	315	(0.03)	979	(0.03)	1406	(0.03)	269	(0.03)	238	(0.04)	3207	5
2007	313	(0.03)	991	(0.03)	1417	(0.03)	260	(0.03)	172	(0.03)	3153	4
2008	329	(0.03)	945	(0.02)	1364	(0.03)	272	(0.03)	174	(0.03)	3084	4
2009	309	(0.03)	1.037	(0.03)	1283	(0.03)	270	(0.03)	117	(0.02)	3016	4
2010	335	(0.03)	1.213	(0.03)	1443	(0.03)	248	(0.03)	94	(0.02)	3333	2
2011	414	(0.04)	1.318	(0.03)	1440	(0.03)	273	(0.03)	59	(0.01)	3504	1
2012	387	(0.03)	1.398	(0.04)	1636	(0.03)	325	(0.04)	46	(0.01)	3792	4
2013	505	(0.04)	1.628	(0.04)	1885	(0.04)	354	(0.04)	60	(0.01)	4432	1
2014	473	(0.04)	1.600	(0.04)	2055	(0.04)	335	(0.04)	28	(0.00)	4491	3
Total	**11,287**		**37,960**		**48,626**		**8116**		**6053**		**112,042**	

[1] The absolute values are in the first column of each element. [2] The relative values are put in the other with brackets.
[3] The dominant code belongs to relative values.

Appendix D

Table A4. The Disaggregation of the Associated System in Construction in the US from 1976 to 2014 with Absolute and Relative Values of Patents on Each Element Per Year.

Year	Machines (1)		Materials (2)		Tools (3)		Total	The Dominant Code
1976	311 [1]	(0.03) [2]	676	(0.02)	181	(0.02)	1168	1 [3]
1977	332	(0.03)	702	(0.02)	165	(0.02)	1199	1
1978	337	(0.03)	788	(0.02)	128	(0.02)	1253	1
1979	293	(0.02)	704	(0.02)	133	(0.02)	1130	1
1980	269	(0.02)	728	(0.02)	149	(0.02)	1146	1
1981	237	(0.02)	724	(0.02)	167	(0.02)	1128	3
1982	254	(0.02)	714	(0.02)	133	(0.02)	1101	1
1983	194	(0.02)	696	(0.02)	126	(0.02)	1016	3
1984	245	(0.02)	751	(0.02)	138	(0.02)	1134	1
1985	256	(0.02)	816	(0.02)	154	(0.02)	1226	1
1986	228	(0.02)	914	(0.02)	144	(0.02)	1286	2
1987	225	(0.02)	1006	(0.02)	168	(0.02)	1399	2
1988	255	(0.02)	1221	(0.03)	183	(0.02)	1659	2
1989	228	(0.02)	1258	(0.03)	213	(0.03)	1699	2
1990	261	(0.02)	1328	(0.03)	180	(0.02)	1769	2
1991	285	(0.02)	1321	(0.03)	208	(0.03)	1814	2
1992	251	(0.02)	1202	(0.03)	172	(0.02)	1625	2
1993	256	(0.02)	1219	(0.03)	180	(0.02)	1655	2
1994	303	(0.02)	1259	(0.03)	214	(0.03)	1776	2
1995	255	(0.02)	1457	(0.03)	205	(0.03)	1917	2
1996	306	(0.02)	1230	(0.03)	230	(0.03)	1766	3
1997	294	(0.02)	1308	(0.03)	248	(0.03)	1850	3
1998	339	(0.03)	1143	(0.03)	249	(0.03)	1731	3
1999	344	(0.03)	1235	(0.03)	263	(0.03)	1842	3
2000	328	(0.03)	1376	(0.03)	252	(0.03)	1956	3
2001	376	(0.03)	1515	(0.03)	276	(0.04)	2167	3
2002	355	(0.03)	1510	(0.03)	301	(0.04)	2166	3
2003	320	(0.03)	1269	(0.03)	208	(0.03)	1797	2
2004	310	(0.03)	1286	(0.03)	209	(0.03)	1805	2
2005	296	(0.02)	1182	(0.03)	150	(0.02)	1628	2
2006	328	(0.03)	1203	(0.03)	180	(0.02)	1711	2
2007	356	(0.03)	1271	(0.03)	176	(0.02)	1803	1
2008	319	(0.03)	1210	(0.03)	138	(0.02)	1667	2
2009	395	(0.03)	1296	(0.03)	178	(0.02)	1869	1
2010	387	(0.03)	1330	(0.03)	216	(0.03)	1933	1
2011	424	(0.03)	1452	(0.03)	178	(0.02)	2054	1
2012	457	(0.04)	1414	(0.03)	250	(0.03)	2121	1
2013	531	(0.04)	1419	(0.03)	294	(0.04)	2244	1
2014	564	(0.05)	1326	(0.03)	282	(0.04)	2172	1
Total	**12,.304**		**44,459**		**7619**		**64,382**	

[1] The absolute values are in the first column of each element. [2] The relative values are put in the other with brackets.
[3] The dominant code belongs to relative values.

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