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Exploring role of Eco-friendly elevators in literature

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***Abstract**: This study is exploring the role of Eco-friendly elevators in literature based on an analysis of 113 papers published in scholarly journals drawn from the Scopus database. This is the first study which used a bibliometric analysis to review the academic literature in the elevator system research field. The analysis started with the gradual classification of collected papers according to the multi-objective problem of vertical transportation and a citation analysis. Determining predominant themes and sub-themes was conducted by bibliometric analysis based on the co-occurrence of title words inside bi-dimensional matrix. The obtained results highlighted an emerging research cluster (energy utilization) one of the most important for future elevator system development. This cluster addresses technological advances of elevators and predicts Eco- elevator technologies to be widely used in near future. This research could be very useful to foster in-depth knowledge of Eco-friendly elevators.*

***Keywords**: Eco-friendly elevators, elevator systems, literature review, bibliometric analysis, thematic evolution.*

Istraživanje uloge ekološki prihvatljivih liftova u literaturi

***Apstrakt**: Ova studija istražuje ulogu ekološki prihvatljivih liftova u literaturi na osnovu analize 113 radova objavljenih u naučnim časopisima iz baze podataka Scopus. Ovo je prva studija koja je koristila bibliometrijsku analizu za pregled*

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akademske literature u oblasti istraživanja sistema liftova. Analiza je započela postupnim razvrstavanjem sakupljenih radova prema problemu višeciljne optimizacije vertikalnog transporta i analizom citata. Određivanje dominantnih tema i podtema sprovedeno je bibliometrijskom analizom na osnovu zajedničkog pojavljivanja reči u naslovima razmatranih radova unutar dvodimenzionalne matrice. Dobijeni rezultati su istakli istraživački klaster u razvoju (iskorišćenje energije) kao jedan od najvažnijih za budući razvoj sistema liftova. Ovaj klaster se bavi tehnološkim napretkom liftova i predviđa da će se tehnologije eko-liftova široko koristiti u bliskoj budućnosti. Ovo istraživanje bi moglo biti veoma korisno za posticanje dubljeg znanja o eko-liftovima.

***Ključne reči**: Ekološki prihvatljivi liftovi, sistemi liftova, pregled literature, bibliometrijska analiza, tematska procena.*

1. Introduction

Very common inquiry in the last decade is "What do Components of Sustainable Design for Green/Smart Buildings"? Apart all others the present study would like to be concentrate of the Energy, i.e. Strategies to ensure and improve the building's energy performance and reduce energy consumed, as well as identify opportunities to use renewable energy sources (Kubba, 2016). Most specifically, the main goal of this paper is to highlight the role and importance of elevators in buildings, especially Environmentally/Eco-Friendly Elevators in the content of their development in the published studies. If the building is taller, the role of elevators becomes more important not only for the efficient realization of people's movement between floors, but also in relation to energy consumption. As elevators account from a few percent up to 10 percent of building energy use, then their overall efficiency should be optimized. In that way, although the results showed that elevator energy efficiency and elevator environmental friendly are dominant in more than 60% of the 101 analyzed, but very broadly selected papers in (Zrnic et al., 2023), this survey study is more dedicated to analyzing the results from previous indexed studies.

Looking into basic elevators literature (Barney and Al-Sharif, 2016; The Vertical Transportation Handbook, 2010) known as lift traffic engineering/vertical transportation it is easy to adopt its the seven pillars such as *Round trip time evaluation*, *Design procedure* (no. of elevators in the group with speed and capacity), *Performance parameters* (the average waiting time and the average travelling time), *Traffic surveys* (based on the passenger arrival process), *Simulation* (assess the performance of elevators traffic systems), *Group control*

and *The design of high rise buildings*. Further the selection of the most environmentally friendly elevators during the building design phase is very useful. Such an elevator will significantly contribute to the achievement of appropriate performance for Sum-Zero energy building ("a building that produces at least enough emission-free renewable energy to cover the emission generated by its non-renewable energy sources") (Khazaii, 2014). Therefore, how it could be possible that Eco-friendly elevators present the more common sustainable solution of vertical transportation. In that way, their main features could be specified as: machine-room-less (MRL) elevator; Gearless traction motor; drive systems that regenerate energy; computerized precision traffic control that optimizes the performance of a group of elevators and decreases light-load trips; in-cab sensors and software that make the elevator go into sleep mode when not in use, turning off the music, video, lighting, and ventilation; and destination dispatch control software to improve passenger traffic flow (Al-Kodmany, 2023a,b,c; Zrnic et al., 2023).

Everyday some new digital and Artificial Intelligence-based enhancements have been harvested and included in a new generation of elevator technology. Each next generation of elevator technology improves elevator systems to be faster, safer and comfortable with more personalized rides. Firstly, energy-efficient hardware is recognized which appears through replacement of DC (direct current) motors with more efficient AC (alternating current) motors; using geared or gearless traction elevators (where second one can be 50% smaller); employ MLR elevators; apply regenerative drive as very energy-efficient technology; recommendation of special design for elevator ropes (e.g. fiber/steel/polyurethane ropes/ "Ultra Rop"); design of Double-Deck Elevators; use TWIN system (TWIN is an elevator system); installing Energy-efficient light-emitting diode (LED); using computerized role guides; breaking system and air pressure differential (see more in Al-Kodmany, 2023a,b,c; Zrnic et al., 2023). Secondly, energy-efficient software solutions are focused on the elevator traffic optimization because the elevator's cycle and traffic performance significantly impacts energy consumption. In that way, these software solutions could be very useful for optimal traffic modeling based on acceptable average waiting time, round-trip time, up-peak traffic, average travel time, empty trips related to energy consumption models among others. Therefore, simulation modeling and the application of new software solutions significantly support the optimal elevators operation regime through Destination Dispatching Systems; People flow solutions; Standby Mode; Predictive maintenance applications suites; Elevator monitoring system based on the Internet of Things; Elevator Group Control System; The supercapacitor-based elevator energy storage system (see more in Al-Kodmany, 2023a, b, c; Zrnic et al., 2023).

According to studied review papers (Al-Kodmany, 2015; Fernandez and Cortes, 2015; Al-Kodmany, 2023a, b, c; Zrnic et al., 2023), a significant gap was found which indicates that there is not Meta analysis of scientific publications for elevators system. This analysis provides a united estimate of effect, an objective and heterogeneity between results, while some relevant studies could be omitted or some others selected by bias. Further, summary data is usually used rather than individual ones. Then, a bibliometric analysis was conducted in the paper to carry out the search on relevant databases, perform the gathering and filtering of dataset, deeply screen the dataset, manual browsing the results of the dataset, final dataset selected and conduct the analysis. This analysis allows a quantitative way of measuring study impact, relevant scientific information on research, highlighting main components of the study like keywords, predicting the future research directions, indicating on the development trend of research areas among others.

There is a need for a survey study to determine the achieved development trends in elevators system research. This survey could describe a clear scoping of progress and challenges in green elevator technologies and to give a state of knowledge of the scientific research. All of that would distil results obtained in the selected dataset papers. To confirm these statements the elevator system research field provides insights in its thematic evolution using bibliometric software known as the Bibliometrix R package as a very efficient tool.

The rest of the paper is structured as follows. The research methodology is presented in Section 2. The results of conducted bibliometric analysis and classification of selected papers are summarized with discussions in Section 3. The previous achievements with future research directions are presented in Conclusions.

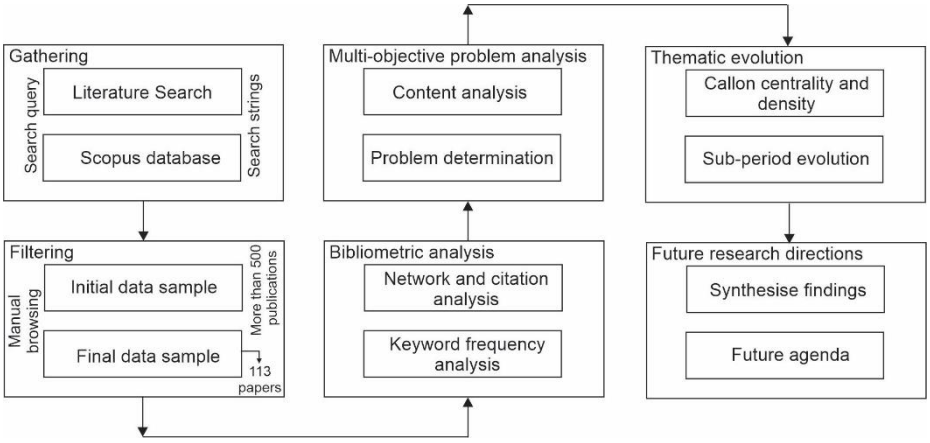
2. Methodology

The search for scientific papers was carried out through the Scopus database. The search methodology and process analysis are shown in Figure 1. The first step is based on the selected keywords and search strings which are implicitly or explicitly linked to elevators-related papers. The final data sample was collected based on a systematic and reproducible way (through gather and filter procedures). The Scopus database was queried (https://www.scopus.com/) as an comprehensive dataset to find elevator-related papers by the following queries (“passenger/freight elevators/lifts” or “green elevators/lifts” or “Eco-Friendly elevators”) and search strings (“elevators inside buildings AND its

practice", "elevators design AND traffic patterns", "modelling concept of vertical transport AND elevators", "New sustainable design of elevators AND recent technological advances", "smart elevators AND elevator system"). This search was conducted in the keywords, abstract and title, based on English publications only.

The initial data sample which collected was based on more than 500 publications. Then, a main exclusion criterion was determined as "only to journals' papers could be included in final dataset". After applying this criteria and further manual screening (based on eligibility and relevance of contents), the final data sample contained 113 papers (i.e. 109 journals' papers and 4 papers from Book series issued by respectable publishers). According to that two files (.csv and .bib files, each with metadata for 113 papers) were ready for further handling and analysis.

Figure 1. Flow charts of search methodology and process analysis



In the next step, all papers in the dataset have been classified as relevant for a qualitative analysis on their research focus as shown in Table A1 (Appendix A). The vertical transportation (VT) problem defined in (Barney & Al-Sharif, 2016) and analyzed in (Zrnic et al., 2023) is a multiple constraint-multiple-objective problem that aims to produce categorization of 113 papers as shown in Table A1: Safe (S); Functional (F); Reliable (R); Cost effective (CE); Able to meet the passenger performance requirements (PPr); f) Able to use the smallest possible core space of the building (SBR); Energy efficient (EE) (Barney & Al-Sharif, 2016) and Environmental friendly (EF) (Zrnic et al., 2023). The categorized papers presenting models that could be utilized as a potential

component of previously mentioned multiple-objective problems were included in the dataset. These papers collected in Table A1 (Appendix A) were reviewed to gather additional bibliometric information in order to conduct deeper analysis of their influence.

Further, bibliometric analysis is conducted. Using annual scientific production with average citations per year, keyword frequency analysis, network and citation analysis as some of the main bibliometric indicators, the present study formed the basis for analyzing conceptual structure of selected dataset. In that way, this structure which is based on the co-occurrence of key terms (keywords plus, authors' keywords, keywords in the title or abstract of the papers including any combination of them) represent the content of the papers. If two papers have more common key terms/keywords, they are more similar which indicates the same research area/field at a higher level. Hence, the co-word network represents more keywords in a paper, which usually appear together. It provides possibility to recognize various themes related to a research area/field by using some clustering (e.g. Louvain and Leiden among others). In accordance with that, themes visualization is depicted for three sub-period, while strategic diagrams are built related to the main subject of this paper.

The last, but not the least step to identify the future research directions is emphasized through mapping of the changes in keywords and discussion of strategic diagrams for thematic evolution. Although the known challenges in the near future using hardware and software technologies on the sustainable elevator design have been highlighted in the previous survey study (Zrnic et al., 2023), a great cohesion of the themes evolution in sustainable elevator design show huge potential for future research directions which could be determined by bibliometric analysis.

3. Results and analysis

This survey study contains a dataset of 113 papers as shown in Table A1 (Appendix A). All of these papers are deeper reviewed and represent 109 journal papers and 4 papers from Book series according to the classification of Scopus database. Less than fifty percent of papers (i.e. 56) are already considered in (Zrnic et al., 2023) but not from the bibliometric aspect, whilst 57 new papers were included in the dataset. In such cases, papers were focused on more than one category related to vertical transportation problems defined in (Barney & Al-Sharif, 2016) and analyzed in (Zrnic et al., 2023) as a multiple constraint-multiple-objective problem which were previously described. In that

way, the research profile of each paper is highlighted to examine the relevant problem investigated as given in Table A1. These results for each paper contain bold (√) and normal (√) marks, where the bold mark depicts the primary subject, while normal mark indicates secondary point of view related to research problems. If there were no second problems considered in some papers, they were not noted (Zrnic et al., 2023).

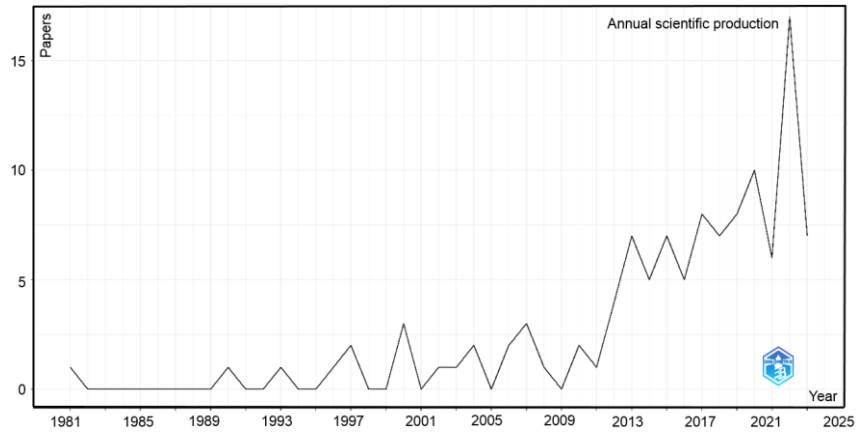
After putting this dataset in the context, it is very important to emphasize what bibliometric techniques are. Each indexed publication contains bibliographic data which can be analyzed by bibliometrics. This analysis may be conducted to investigate social and intellectual aspects of papers in the dataset. First one always contains authors, institutions and countries information, while the second treats scientific production and citations among others. Further, there are bibliometric methods, network analysis and science mapping whose combination may products scientific production using conceptual (e.g. thematic maps), intellectual (e.g. co-citations) and social (e.g. various collaboration maps) structure of the papers in dataset. The results of some of the bibliometric methods and techniques will be presented further.

3.1. Citations and scientific production

The analysis of citations is provided in Table A1 for each paper up to August 2023. A total of 1296 citations were collected from 113 papers or an average 11.5 citations per paper from the Scopus database. On the other side, a total 2012 citations is collected or 19.5 citations per paper from Google Scholar database. Which means that papers were cited 1.7 times more in Google Scholar database. The most cited papers are Kang and Sul (2000) with 63 citations, Al-Kodmany (2015) which collected 60 citations and Siikonen (1993) counted 51 citations from the Scopus database. The most productive papers per yearly citations output are Gupta et al. (2022) and Al-Kodmany (2015) each with 7.5 citations per year, followed by Zhou et al. (2018) and Yang et al. (2017) each with 6.1 and 6 citations per year, respectively (based on the Scopus database).

A fast-growing trend of elevator systems research is observed after 2012 as given in Figure 2. A further intensified scientific production is noticeable around 2020 where the number of papers peaking in 2022 at 17 ones.

Figure 2. Annual scientific production



Source: Authors' elaboration using Bibliometrix R package & Biblioshiny, Aria and Cuccurullo (2017)

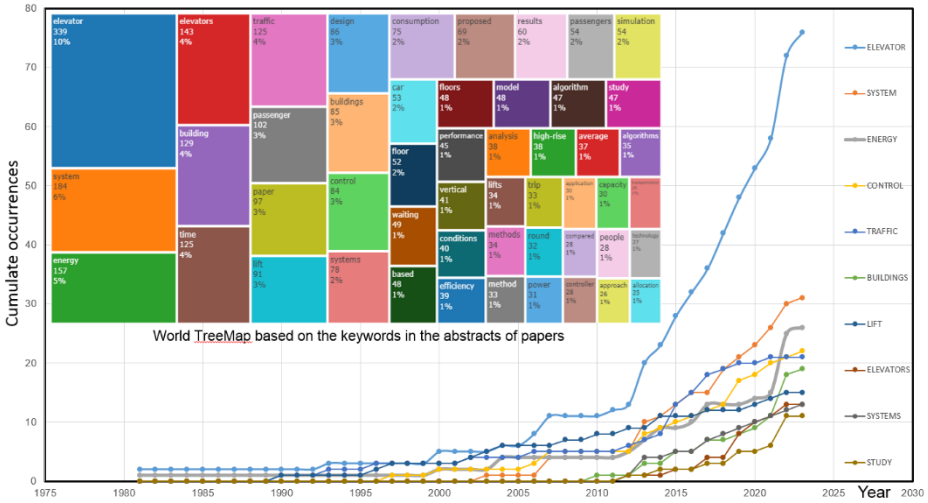
3.2. Keywords analysis

To identify contextual links among papers in the dataset the analysis of the co-occurrence of keywords is conducted. In order to analyze the research trends and depict focus on thematic evolution this is a significant part. The distribution frequency of the leading keywords which appears in the titles of the papers as shown in Figure 3 implies the papers in the dataset focusing on the research subject and some related issues. From the beginning of this century, an important growth could be noticed in the number of keywords such as "elevator", "system" and "energy" among others. This dynamic was also investigated by verifying which keywords have associated the number of total link strength which is proportional to frequency of occurrence in the analyzed period.

The word ThreeMap of keywords that received elevator systems interest from researchers is shown inside Figure 3 to confirm the dynamic of the most relevant keywords. According to that, "system", "energy", "building", "time", "traffic" and "passengers" are common elevator system keywords. Further, "design", "control", "consumption", "car", "floor", "waiting" and "performance" present other parts of significant keywords. This shows the development potential of the elevator system. The importance of the large amount of data that needs to be processed and analyzed is particularly emphasized. The importance of process modeling and simulation is also highlighted, which can,

with the application of new technologies, increase the overall elevator system efficiency and significantly reduce energy consumption.

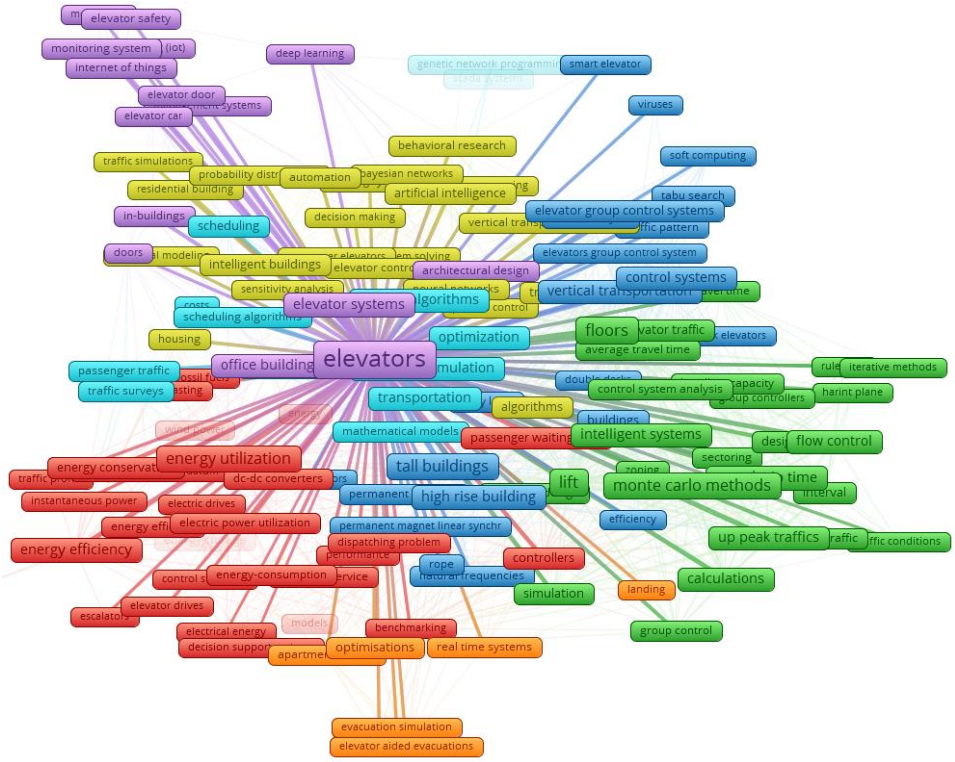
Figure 3. The dynamic of the most relevant keywords in the title of the papers and world ThreeMap based on the keywords in the abstracts of papers



Source: Authors' elaboration using Bibliometrix R package & Biblioshiny, Aria and Cuccurullo (2017)

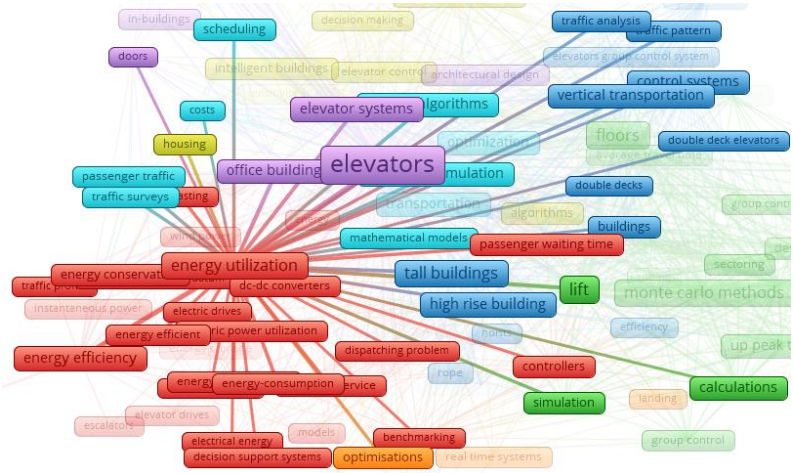
Co-occurrences networks of the index keywords as shown in Figures 4 and 5 using Scopus data and the VOSviewer software are given. Co-occurrence index keywords with full counting which have occurred two or more times are presented. These figures indicate correlation maps between the index keywords and contain a "co-occurrence or co-word evaluation" of the keywords, pointing to several significant themes in the elevator system. The distance between two keywords (two nodes) is approximately inversely proportional to the similarity (relatedness in terms co-occurrence) of the keywords. Hence, keywords with a higher rate of co-occurrence tend to be found closer to each other and size of them in the map depends mainly on their presence in the related topic. The keywords which occur in the map center or close to that, forming main clusters in dataset (Table A1) according to feature that the VOSviewer provides a clustering function, which assigns keywords to clusters based on their co-occurrence (van Eck and Waltman, 2010).

Figure 4. Co-occurrence index keywords - full counting network visualization



Source: https://www.vosviewer.com (van Eck and Waltman, 2010)

Figure 5. Part of Figure 4 which underlined energy utilization



Source: https://www.vosviewer.com (van Eck and Waltman, 2010)

Therefore, this analysis is generated by 140 frequently appeared keywords grouped into seven clusters, which are the mainstream research directions inside elevator systems. The seven keyword clusters have identified the different research focuses. Red Cluster comprises 33 keywords focusing mainly on the main subject of the paper and also any of the significant items related to elevator systems such as "energy utilization", "energy efficiency", "energy management", "energy conservation", "energy consumption" among all others (This cluster is separately shown in the Figure 5). Green Cluster contains also 26 items that predominantly emphasize the use of typical elevator system keywords. Dark Blue Cluster covers 23 nodes focusing directly on the elevator traffic analysis, new technologies application in elevator systems and various techniques to solving traffic models. Yellow Cluster consists of 22 keywords, which engage in "the artificial intelligence", "Bayesian network", "intelligent building", "neural network", "automation" and "traffic control" among others. Purple Cluster includes 15 nodes that focus on "elevator systems", "elevator safety", "internet of things", "deep learning", "monitoring systems" and so on. Light Blue Cluster consists of 14 keywords related to "computer simulation", "genetic algorithms", "genetic network program", "mathematical modeling", "scheduling" etc. Orange Cluster contains seven items, where the first one is focused on "optimization", "real time system", "elevator aided evacuation", "evacuation and fire simulation", "simulation" among others.

3.2. Thematic evolution

The thematic evolution of the papers in the dataset is conducted and the results of this analysis are presented in Table 1 and Figures 6 - 8. This analysis has been focused on the three periods (i.e. the first one from 1981 to 2014; the second one from 2015 to 2020 and the third one from 2021 to August 2023). Using the Bibliometrix R package (Aria and Cuccurullo, 2017), this analysis treated 250 keywords in the title of papers from the dataset. Cluster frequency was set to minimum 3 with index weighted by word-occurrences set to 0.1. A few keywords are shown per each cluster.

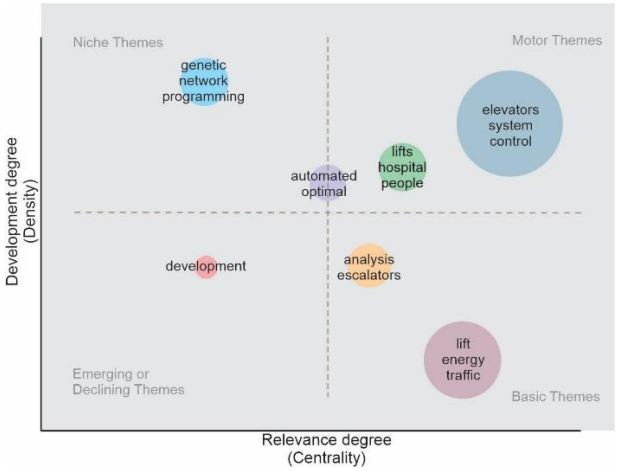
If frequency of occurrence is small for some keywords, it means they have no significant impacts on the core themes. On the other hand, the keywords which have an adequate level of frequency of occurrence (threshold which may be arbitrary) are grouped into clusters which could be limited with arbitrary number of keywords because this number usually determines the number of keywords which will appear in the cluster (to be visible). The name of the theme is always determined by the keyword with the maximum frequency of occurrence.

There is a strategic diagram based on the Callon centrality and density to analyze the motor themes, the niche theme, the emerging or declining themes and the basic themes (Callon et al., 1991; Cobo et al., 2011). This diagram is divided into four quadrants. Each quadrant represents different types of themes (the first quadrant has on the upper right-hand corner of the plane and represents Motor themes - These themes have high levels of centrality and density because they are highly relevant and well developed; the second quadrant has on the upper left-hand corner of the plane and represents Nische themes - These themes have low centrality and high density because they are the highly developed but not very relevant; the third quadrant has the lower left-hand corner of the plane and represents Emerging/declining themes - These themes have low centrality and low density because they are weakly developed internal and external ties; and the fourth quadrant has the lower right-hand corner of the plane and represents Basic themes - These themes have low levels of density and high levels of centrality because they are low developed but very relevant themes) (see more in Callon et al., 1991; Cobo et al., 2011).

Table 1. Description of the themes during considering periods

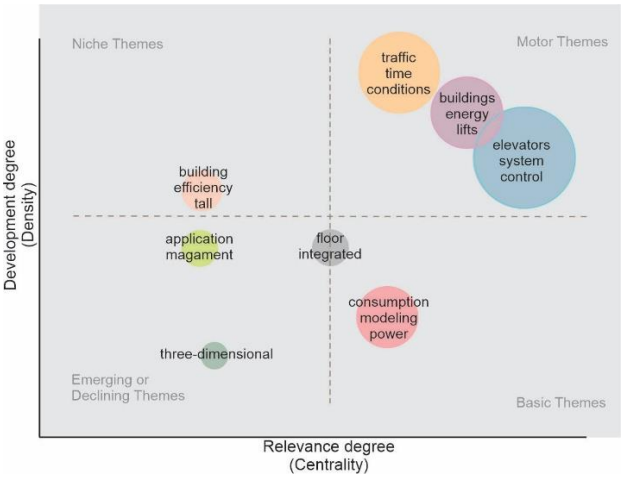
The first period, 1981-2014 based on results in Figure 6	**The second period, 2015-2020 based on results in Figre 7**	**The third period, 2021-2023, based on results in Figure 8**
Motor themes	Motor themes	Motor themes
There are a few themes in the two clusters: "elevators", "system" and "control" are predominant in the central cluster. One smaller cluster partially belongs to it: "automated" and "optimal".	The same cluster stays stably positioned. Two new clusters have very good levels of density and centrality. "Energy", "buildings", "traffic" and "time" appear as new themes.	The two same clusters stay stably allocated although the new cluster from the second period is a little lost to density but its scope is bigger. The two new clusters came, both of them are related to "performance measures" and "smart technology" in "high-rise buildings".
Dominant position of two clusters, while one is very close to centrality (3rd third sub-period) with average levels of centrality and density.		
Niche themes	Niche themes	Niche themes
Contains one cluster with three interesting themes: "programming", "genetic", "network". A slightly smaller cluster partially belongs to it with the themes "automated" and "optimal".	There are three themes: "building, "efficiency" and "tall".	Contains one cluster which has three themes: "algorithm", "prevention" and "transportation". Also one cluster slightly touches this quadrant with the two interesting themes such "modeling" and "solution".
There are not many clusters but the existing ones express some potential.		
Emerging/declining themes	Emerging/Declining Themes	Emerging/Declining Themes
There is one theme: "development".	Contains the two clusters. The first one with the two themes: "application" and "management". The second one has one theme: "three-dimensional". A slightly smaller cluster partially belongs to it with the themes: "floor" and "integrated".	There are four clusters. Two first have per the two themes: "modeling" and "solution"; and "elevators and "improve. Two second clusters have one theme each: "smart" and "technology".
These clusters include several studies and their development is on the way to being realized.		
Basic themes	Basic themes	Basic themes
The two clusters exist. The first one has the three themes: "lift", "energy" and "traffic". Second cluster contains the two themes: "analysis" and "escalators".	There is one cluster which has the three themes: "consumption", "modeling" and "power". A smaller cluster partially belongs to it with the theme "floor" and "integrated".	Only one cluster exists with the three themes: "study", "lift" and "residential". Also one cluster slightly touches this quadrant with the three interesting themes such "analysis", "performance" and "ropeless".
Although it does not contain many clusters and themes, some of them are very significant as "energy", "consumption" and "modeling".		

Figure 6. Thematic map (1981-2014)



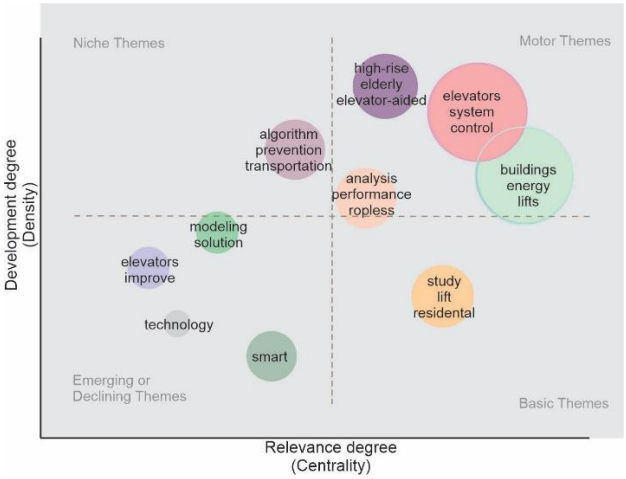
Source: Authors' elaboration using Bibliometrix R package & Biblioshiny, Aria and Cuccurullo (2017)

Figure 7. Thematic map (2015-2020)



Authors' elaboration using Bibliometrix R package & Biblioshiny, Aria and Cuccurullo (2017)

Figure 8. Thematic map (2021-2023)



Authors' elaboration using Bibliometrix R package & Biblioshiny, Aria and Cuccurullo (2017)

4. Conclusions and further research

A bibliometric analysis is conducted to investigate the elevator system. This is the first study which used a bibliometric review of the academic literature in the elevator system research field. As pointed out in (Zrnic, 2023) a several studies have analyzed this subject related to development new technologies (e.g. Al-Kodmany, 2023a), or elevator group control systems (Fernandez and Cortes, 2015), but this approach which gives deep bibliometric analysis has not been studied. The main results which revealed in this survey study show credible scope of analyzed academic studies, their subject related to elevator system the multiobjective problem, citations analysis, deep keyword consideration (dynamic of the most relevant keywords and world ThreeMap) with co-occurrence network visualization and conceptual structure through thematic evolution of elevator system research based on bi-dimensional matrix. One of the most important results is highlighted by a specific red cluster in keywords co-occurrence network map as shown in Figure 4. This cluster named *energy utilization* depicts the relationship between Eco-elevator development trends and elevator systems in general and reveals current trends and further trends in the elevator industry.

The results obtained in this study are based on relevant dataset and their analysis, an actual scientific methodology and using the two much known bibliometric software, that way all results are results reproducible and verifiable.

4.1. Synthesize findings

Emerging research cluster within the elevator systems research was revealed in scientific literature named *energy utilization* which addresses technological advances of elevators to predict Eco- elevator technologies. Its links with other sub-clusters such as energy efficiency, energy management, energy conservation and energy consumption (see more in Figure 5) make it possible to transform from standard to new eco-design of elevator systems in near future. There are more other sub-clusters which explore the impact of green and smart lift technologies and their application in high-rise and smart buildings (see more in Table A1).

4.2. Limitations

This survey study has a few limitations. It can have an impact on the interpretation of the obtained results. Process of gathering and filtering data could be arbitrary and subjective. This study was concentrated mostly on journals' papers from the Scopus database. That way, some important study could be omitted. Also during searching there may be some limitations (e.g. selection of searching keywords and strings). The main intention in this study has been to gain current and future trends in general, and even if some paper has not been found, its influence can mainly be determined by collected papers. Mostly the keywords were used in analysis and whether the optimal clustering algorithm is always chosen may be questionable.

4.3. Future agenda

Although the trend topic seems to focus on developing new elevator technologies, it is yet questionable how widely adopted these technologies and innovations are into the elevator system. Therefore, each stakeholder could give some contributions related to technical, technological, institutional, social and cultural aspects including standardization and legislation, in order that new technologies be widely applied in elevator systems. It would be a good initiative for the efficient operation of the elevators, the reduction of energy consumption and the use of alternative energy sources in the near future.

This bibliometric analysis could be extended in the future research with the dataset extending, comparing the obtained results with extended dataset, the

process how some thematic items (Figures 6 - 8) could be more central in order to be more important for elevator systems, and relevance and usefulness of this kind of research and its more application in the practice. As technologies are rapidly changing, as are elevator requests, then future research should be concentrated to perform conceptual structure maps by multiple correspondence analysis.

Appendix A

Table A1. Classification according to the multi-objective problem of VT

Refrences	Issued	N_s	N_{GS}	S	F	R	CE	PPr	EE	EF
Van Houten et al. (1981)	1981	41	109				√		**√**	
Peters (1990)	1990	21	48		√			**√**		
Siikonen (1993)	1993	51	101		√	**√**				
Peters et al. (1996)	1996	5	9		√			**√**		
Schofield et al. (1997)	1997	17	40		**√**			√		
Brown et al. (1997)	1997	0	1		√			**√**		
Kang & Sul (2000)	2000	63	100		**√**			√		
So & Li (2000)	2000	5	9		√				**√**	
Lozzi & Briozzo (2000)	2000	1	1	√		**√**				
So & Suen (2002)	2002	3	4		√			**√**		
Chu et al. (2003)	2003	17	41					**√**		
Al-Sharif (2004)	2004	10	26		√				**√**	
Al-Sharif et al. (2004)	2004	14	51		√				**√**	
Tyni & Ylinen (2006)	2006	41	94					√	**√**	
Imrak & Ozkirim (2006)	2006	8	14		**√**			√		
Hamdi & Mulvaney (2007)	2007	12	19					**√**		
Yu et al. (2007)	2007	5	7		√			**√**		
Zhou et al. (2007)	2007	4	7		√			**√**		
Imrak (2008)	2008	12	12		√			**√**		
Al-Sharif & Seeley (2010)	2010	13	26		**√**			√		
Godwin et al. (2010)	2010	0	0		**√**			√		
Olander & Eves (2011)	2011	27	49					**√**		√
De Almeida et al. (2012)	2012	50	94		√				**√**	
Wang et al. (2012)	2012	14	21		**√**	√				
Cortes et al. (2012)	2012	2	32		√			**√**		
Kuusinen et al. (2012)	2012	24	35		√			**√**		
Cortes et al. (2013)	2013	23	30		√			**√**		
Adaka et al. (2013)	2013	34	51		√				**√**	
Fernandez et al. (2013)	2013	14	21		√			**√**		
Zhang & Zong (2013)	2013	25	35					√	**√**	
Al-Sharif et al. (2013)	2013	18	54		√			**√**		
Bolat et al. (2013)	2013	28	42		√			**√**		
Yoo & Park (2013)	2013	1	2					√	**√**	
Al-Sharif & Al-Adem 2014	2014	15	33		√			**√**		
Ahmed et. al. (2014)	2014	15	17						**√**	√

Fernandez et al. (2014)	2014	40	49		√			**√**		
Noppakant et al. (2014)	2014	3	5						**√**	√
Graham (2014)	2014	22	49					**√**		
Al-Sharif et al. (2015)	2015	14	29		√			**√**		
Al-Sharif & Abu Alqumsan (2015a)	2015	11	17		√			**√**		

Legend: N_S - Number of citations from Scopus database up to August 2023; N_S - Number of citations from Google Scholar database up to August 2023; (Vertical transportation multi-objective problem - Safe (S); Functional (F); Reliable (R); Cost effective (CE); Able to meet the passenger performance requirements (PPr); Energy efficient (EE); Environmental friendly (EF), see more in Zrnic et al. (2023))

Source: Scopus and Google Scholar databases and authors' elaboration

Table A1 – Continued.

Refrences	Issued	N_s	N_{GS}	S	F	R	CE	PPr	EE	EF
Al-Sharif & Abu Alqumsan (2015b)	2015	19	44		√			**√**		
Fernandez et al. (2015)	2015	34	52		√			**√**		
Al-Kodmany (2015)	2015	60	95					√	**√**	
So et al. (2015)	2015	13	22		**√**			√		
Kim et al. (2015)	2015	2	3	**√**		√				
Tukia et al. (2016)	2016	19	26					√	**√**	
Al-Sharif et al. (2016)	2016	4	9		**√**			√		
Beamurgia et al. (2016)	2016	10	11		√			**√**		
Rajeesh Kumar et al. (2016)	2016	1	-	√		**√**				
So et al. (2016)	2016	15	20		√			**√**		
Al-Sharif et al. (2017a)	2017	2	13		**√**	√				
Al-Sharif et al. (2017b)	2017	4	11		**√**			√		
Al-Sharif et al. (2017c)	2017	4	9		**√**			√		
Tukia et al. (2017)	2017	6	7					√	**√**	
Ahn et al. (2017)	2017	12	12					√	**√**	
Papanikolaou et al. (2017)	2017	5	6						**√**	√
Rotger-Griful et al. (2017)	2017	13	17						**√**	√
Yang et al. (2017)	2017	37	48		**√**	√				
So et al. (2018)	2018	9	11		**√**			√		
Crespo et al. (2018)	2018	35	42		**√**	√				
Kim et al. (2018)	2018	6	7		**√**	√				
Ming et al. (2018)	2018	8	16	**√**		√				
Zhou et al. (2018)	2018	30	40		**√**	√				
Tukia et al. (2018)	2018	17	20					√	**√**	
Al-Sharif et al. (2018)	2018	7	8		**√**			√		
Al-Sharif et al. (2019)	2019	0	0		**√**			√		
Tukia et al. (2019)	2019	9	16						**√**	√
So & Al-Sharif (2019)	2019	7	10		√			**√**		
Kwon & Jung (2019)	2019	0	-	**√**	√					
Sale & Prakash (2019a)	2019	1	0		√			**√**		
Sale & Prakash (2019b)	2019	1	2		**√**			√		
Aleksandrov (2019)	2019	1	3						**√**	√
Bapin & Zarikas (2019)	2019	16	22		√					**√**

Gichane et al. (2020)	2020	15	24	√	√					
Maamir et al. (2020)	2020	3	7						**√**	√
Van et al. (2020a)	2020	8	8					**√**		√
Van et al. (2020b)	2020	8	13					√		**√**
Zubair & Zhang (2020)	2020	11	13						**√**	√
Bapin et al. (2020)	2020	6	6		**√**			√		
Hammoudeh (2020)	2020	2	3		**√**			√		
Kee et al. (2020)	2020	8	8		**√**			√		
Blazquez-Garcia et al. (2020)	2020	17	22						√	**√**
Wut (2020)	2020	1	1						√	**√**
Belmonte & Trabucco (2021)	2021	1	2		**√**	√				
Cortes et al. (2021)	2021	6	10					**√**		
Dalala et al. (2021)	2021	7	9						√	**√**

Table A1 – Continued.

Refrences	Issued	N_s	N_{GS}	S	F	R	CE	PPr	EE	EF
Robal et al. (2021)	2021	3	5					√		**√**
Sorsa et al. (2021)	2021	5	4		√			**√**		
An et al. (2021)	2021	4	4	**√**		√				
Robal et al. (2022)	2022	1	2					√		**√**
Al-Had et al. (2022)	2022	2	2		√	**√**				
Anh et al. (2022)	2022	3	3						**√**	√
Chandirasekeran & Shridevi (2022)	2022	0	1					√		**√**
Fang et al. (2022)	2022	2	4	**√**						√
Hunt et al. (2022)	2022	9	17						**√**	√
Lee et al. (2022)	2022	7	8		√	**√**				
Makar et al. (2022)	2022	4	7						**√**	√
Tomatis et al. (2022)	2022	0	1			√				**√**
Khonjun et al. (2022)	2022	3	4					√	**√**	
Lai et al. (2022)	2022	3	3	√						**√**
Chatziparasidis & Sfampa (2022)	2022	2	2	√						**√**
Basov et al. (2022)	2022	1	1					√		**√**
Shilpa et al. (2022)	2022	0	0						√	**√**
Gupta et al. (2022)	2022	15	16	**√**						√
Ang et al. (2022)	2022	6	8						**√**	√
Beamurgia et al. (2022)	2022	0	0					√	**√**	
Al-Kodmany (2023)	2023	0	0						√	**√**
Fang et al. (2023)	2023	0	1	**√**	√					
Kropotin & Marchuk (2023)	2023	1	4						√	**√**
Xu et al. (2023)	2023	1	2				**√**	√		
Maleki et al. (2023)	2023	1	1						**√**	√
Erenchun et al. (2023)	2023	0	0		**√**			√		
Berardi et al. (2023)	2023	0	0					**√**		

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