State of the Art of Artificial Intelligence Use on Smart Sustainable Cities: literature database creation using LLMs

Estado da Arte do Uso de Inteligência Artificial em Cidades Inteligentes e Sustentáveis: criação de base de dados literária usando LLMs

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Abstract

As technology advances, Artificial Intelligence (AI) has become a crucial tool for process development and optimization across different fields. In the quest to make cities more resilient and prepared for upcoming challenges, numerous projects have applied AI-technologies for the areas of energy, environment, traffic and mobility and others. In order to better understand the state of the art in this area, the current study set out to gather a number of scientific publications about the application of AI in Smart Sustainable Cities. Using Large Language Models (LLMs), which are also regarded as AI, the papers were divided into 17 distinct categories. Consequently, an indexation of these papers and their categories, as well as a comparative analysis of the three different LLMs is presented.

Keywords: Artificial Intelligence; LLMs; Smart Sustainable Cities.

Resumo

Com o avanço da tecnologia, a Inteligência Artificial (IA) tem se tornado uma ferramenta crucial para otimizar e desenvolver processos em diversos campos. Na busca para obter cidades mais resilientes e preparadas para futuros desafios, diversos projetos tem aplicado tecnologias de IA nas áreas de energia, meio ambiente, tráfego e mobilidade e outras. Para melhor compreender o estado da arte nesta área, o presente estudo visou a coleta e análise de diversas publicações cientificas sobre o uso de IA em Cidades Inteligentes e Sustentáveis. Utilizando as ferramentas de Linguagem de Grande Escala (LLM), também consideradas IA, os artigos foram divididos entre 17 categorias. Consequentemente, será apresentada uma indexação destes artigos e a as categorias a que pertencem, bem como uma análise comparativa entre três LLMs diferentes.

Palavras-chaves: *Inteligência Artificial; Linguagem de Larga Escala; Cidades Inteligentes e Sustentáveis.*

1. Introduction

In order to face imminent problems caused by increasing urbanization in the world, cities have to evolve and apply technological tools in several areas of human life, to become more sustainable, resilient and smart. Although the term Smart City doesn't have a specific definition, most authors agree, in some level, to be a well connected city, which, through sensors and data collection, can generate intelligence for the decision-making process involving energy consumption and distribution, traffic management, safety, health, environment and so (TEIXEIRA *et al, 2022;* AGARWAL *et al*, 2015*)*.

As cities continue to expand and the needs of citizens increase, problems can become more and more complex, pushing human kind to dive further into the possibilities within technology, searching for solutions. Mehta *et al,* 2021, argue that, although human life on Earth is a natural occurrence, its survival and maintenance depend on the intelligence of its mind. Therefore, the advent of Artificial Intelligence can be seen as the expansion of humans' five senses and their minds, transferring activities once performed by humans into machines.

The use of Artificial Intelligence than becomes explored in the context of creating innovative and efficient initiatives for Smart Sustainable Cities. Using data extracted from a variety of systems and sensors, cities have been implementing smart solutions to reduce their carbon emission (LUZ *et al,* 2023), to efficiently manage their waste (MARANHÃO, *et al,* 2024), to improve health and safety of citizens (BECK *et al,* 2024 and BRUN *et al,* 2023), to improve cities' infrastructure (SHULAJKOVSKA *et al,* 2024 and CHUI *et al,* 2018), and several other initiatives, in order to increase quality of life.

Many specialists have been studying and publishing researches about the this topic, describing the aforementioned initiatives and discussing successes, failures and risks of cities around the world. Thus, it is important to comprehend the state of the art regarding the use of AI in smart sustainable cities' initiatives to better comprehend scenarios in which technology can work together with humanity to extract all of the possibilities it can offer.

Therefore, the present study consists in an extensive research on published scientific papers about the use of Artificial Intelligence in Smart Sustainable Cities aiming to create a relevant database that can be seen as the state of the art regarding this theme. In order to accelerate and simplify the process, AI was also used to compile and categorize this papers into 17 different themes. The categorization process can point out tendencies, such as which themes have been more relevant on the decision-making process to create such a city.

Furthermore, three different AI tools, known as Large Language Models (LLMs), were used throughout this study, allowing also a comparison between them, which can provide insight into their accuracy and limitations.

2. Artificial Intelligence and LLMs

Artificial Intelligence (AI) is a form of Computacional Intelligence (CI) that can offer the analysis of big sets of complex data in real-time. Within the scope of what an AI can do, neural networks (NN) are programs that can be trained to adapt and learn from users' inputs,

in order to adjust weights in its networks to provide results that are closer to the expected (AGARWAL *et al,* 2015).

Another feature is called Fuzzy System (FS), which allows AI to deal with the ambiguity that real life problems bring. It is supposed to minimize the uncertainty of scenarios and broaden the boundaries of data sets, as they would not function as a binary point of view. The third feature of AI is Genetic Algorithm (GA) which would contribute to provide the optimum solution to a problem, or in this study's case, the best output to a prompt (AGARWAL *et al,* 2015).

As AI advances, new programs are being launched offering a friendlier interface to users and increasing the capacity of learning from the programs, which culminates in tools that can be used to accelerate, optimize and catalyze processes once performed strictly by humans.

2.1. **Machine Learning and Natural Language Processing (NLP)**

The process of Machine Learning allows one to extract and analyze data from several sources within the internet through automated computer models (SARKER, 2021). This models are called Natural Language Processing (NLP), which make possible for humans to interact with the machine using their own pattern and idiom in forms of spoken or written language. This models than learn from these inputs and improve their outputs without the user having to perform any programming (JANIESCH *et al.*, 2021; KANG *et al.*, 2020 and SARKER *et al,* 2021).

Machine Learning programs can be used in five different ways: supervised, semi-supervised or unsupervised learning; active learning or reinforcement learnin, depending on how much humans interact with the model. For this study, the semi-supervised method was chosen, as authors provided labels along with the prompt to the LLMs (JANIESCH *et al.*, 2021; SARKER, 2021).

2.2. Large Language Models (LLMs)

One way to simplify the use of machine learning tools available is the use of Large Language Models (LLMs). They are pre-programmed models that can perform tasks through the inclusion of labeled or unlabeled data, using NLP to make it easier for the user to communicate their input desires ((JANIESCH *et al.*, 2021; KANG *et al.*, 2020; SARKER *et al,* 2021; SINHABABU *et al,* 2024).

For this study, three different LLMs were utilized to perform the categorization task. The first one was ChatGPT, an American model offered by OpenAI, trained to Reinforcement Learning from Human Feedback (RLHF). Launched in 2022, it can be used free of charge directly on a webpage. The second model is rather novel, called Deep Seek, it is a Chinese platform, also free of charge, having its latest model being launched in January of 2025 by the company Hangzhou DeepSeek Artificial Intelligence Co. The third model is called CHATAI, and was created by a group of researcher from Meta AI with its latest update in 2023. The latter is offered only to students with a partner university credential.

LLMs have been applied successfully to many tasks regarding document analysis. For example they have been use to rank documents for search engine results in zero-shot as well as in few-shot mode (SINHABABU et al. 2024). In this study they were used to automatically categorize the papers gathered into 17 different categories.

3. Artificial Intelligence Application in Smart Sustainable Cities' Planning

Urban planning is the process of designing and managing the development of cities and urban areas to meet the needs of the community. It includes land use, transportation, environmental, economic, and community development planning. As cities grow, urban planning becomes crucial for ensuring sustainability, efficient resource use, and economic growth. Well-planned cities improve residents' quality of life, support resilience against challenges, and promote environmental responsibility. By incorporating advanced technologies like deep generative learning, urban planning can address complex urbanization challenges and unlock opportunities for innovation and growth (WANG *et al,* 2022).

In light of Artificial Intelligence, new opportunities arise for urban planning, for example the processing of large amounts of data in real-time. That feature can be used for several different purposes, such as to control energy demand and consumption, as well as perform forecasts to improve its efficiency (RAJALAKSHMI, *et al,* 2023).

Safety wise, an example of AI use in Smart Sustainable Cities is the application on security cameras in order to improve accuracy when detecting violence cases, reducing the response time to control them (LIMA *et al,* 2021). Another example would be forecast models that use machine learning to prevent and mitigate disasters in urban locations (SILVA *et al,* 2024).

One of the key factors for Smart Sustainable Cities is the improvement of traffic and mobility, as it is a common denominator for big cities worldwide. AI has been used in this area to develop smart traffic systems, traffic management, improvement of public transportation, smart parking and road safety, for example using machine learning for traffic crash predictions (ARGWAL, *et al,* 2015 and WANG, *et al,* 2025).

There are many other examples of AI use in urban planning, on several different areas, such as improving urban waste management, government decision-making processes, tourism experience enhancement, pavement inspections and climate change mitigation (VENIGLANDA, *et al,* 2024; MOILANEN, *et al,* 2023; BACELAR *et al*, 2024 and NICHI *et al,* 2023). The present study offers a collection of scientific papers discussing all of these initiatives, shedding light on the versatility of the Artificial Intelligence use.

4. Methodological Procedures

The present study set out to achieve three main goals: the first one was to provide the state of the art regarding the use of AI in the context of Smart Sustainable City's initiatives around the world. The second goal was to create a reliable, up to date and efficient collection of scientific papers regarding the theme, which can be used by researchers to further their knowledge on the theme. The third one was to evaluate how LLMs can be useful when creating aforementioned library and how different models respond to the same prompt. The path to achieve all three objectives is described below within four different steps.

4.1. **Step 1: Data Gathering and Preparation**

The first step consisted of gathering a relevant amount of published scientific papers regarding AI use in Smart Sustainable Cities. To increase the number of papers, students of

the Federal University of Minas Gerais (UFMG) were asked to provide each one a paper that discussed the proposed topic during a class in the fifth period of Civil Engineering and in the Sustainability Post-graduate course, where two of the authors taught. Each student had to find the paper, read it and provide a brief analysis and presentation. Both students from the graduate and undergraduate levels participated. The keywords used were “smart cities”; “AI use on smart cities”; “sustainable cities”; “AI use on sustainable cities”, both in English and Portuguese. The limitations imposed were: only procure published papers on reliable sources (such as Google Scholar, Scielo and The Federal University Repository); only use open access papers; only use peer-reviewed published papers and studies.

At the end of the assignment, 103 papers were collected. A database was then created using an Excel spreadsheet, containing important information of each paper, namely: title; year of publication; author(s); abstract and access link. Every paper received an index number, to identify them within the database. Using the index and the title of papers, CHATGPT was used to determine which ones were duplicated, as students from different classes and courses participated and there was no previous rule of non-repeating the papers. The number then reduced to 75 papers. Next, authors read each title and analyzed weather papers were in fact related to AI use on Sustainable Smart Cities and disregarded the ones that were found not to be related. At the end of this step, the library contained 38 relevant papers and each one was assigned a new index number. Finally, a folder containing each paper with that index was also created. The created database can be found in the Results section of this paper.

For the next step, the database had to be prepared in order to get a better response from the LLMs (KANG *et al,* 2020). The preparation went through the following steps: 1) file Standardization: make sure the text file is compatible with NLP language by creating the spreadsheet using simple and relevant text; 2) cleaning: remove every character that can be misread by the LLM, such as special characters, symbols or links; 3) Misspeling Correction: make sure every word is correctly written in the language chosen for the study to prevent errors by the NLP analysis. English was the chosen language due to it’s capacity of broadening the reach of the study and 4) Tokenization: one can break the text down into smaller sentences or words to improve NLP’s analysis. However, in this case, the entire abstract was provided to the LLM as is, in the original language written, as it was considered already a smaller part of the full paper. The LLMs provided along with the categorization a brief one-sentence explanation of what the paper was about, which can be assigned as a token of the abstract for further analysis.

It is important to point out that, even though AI tools can also be used for translation, authors decided not to translate any text before providing them to the LLMs in order to not impose any tendencies in the analysis. However, as the prompt to the LLMs was given in English, the output was also in the same language.

4.2. **Step 2: Topic Modeling Using LLMs**

Although all of the papers have Artificial Intelligence as a main topic, one of the goals of this study was to relate them into categories, to better assess the state of the art and to identify which themes are being explored in Smart Sustainable Cities. The second step, then, consisted on using LLMs to categorize the papers into different themes.

A previous study had identified 17 themes of Smart Sustainable Cities' initiatives using the analysis of five different indicators models by specialists and oficial organizations (such as ISO). It has also determined a hierarchy between those themes, namely high, medium, low and non-priority, based on how often they were used by the models analyzed (TEIXEIRA *et al*, 2022). This themes were used to segregate the papers and analyze which ones are being more relevant for cities when using AI to build their Smart Sustainable plans. The category "people", present in the previous study, was excluded for this one, as authors found it to be too broad, which could mislead the LLM results. Another category was created, namely "else", to accommodate any paper that the LLM could not place in any of the other ones.

Once the categories were set and the database spreadsheet ready, authors then reduced the text to only the columns of index and abstract, for each paper, by omitting every other column in the spreadsheet. For example: Column 1 (Index) with a number from 1-38 and Column 2 (Abstract) containing the abstract of paper in original language as text data. Then, in each LLM model, an explicit command was given: "separate the following texts into the categories: energy; infrastructure and ICT; environment; health; safety; traffic and mobility; shelter; culture; economy; education; water management; e-government; waste management; leisure; tourism; fire and emergency response; else". Every LLM replied with variations of "please provide the texts". This method is known as multi label classification, when NLPs are provided with more than two labels and each text can be assigned to one or more of them (SARKER, 2021). No further prompts were given at this time, using a technique called "one-shot", when the first output is considered the final result. There is also a possibility of the user inserting new prompts to refine the output, in case of unsatisfactory results, which would be considered "few-shots", training the LLM during the process (SHINHABABU, 2024).

Authors then pasted the index and abstract of every paper into the database and extracted the results from the LLM. This procedure was performed using three different LLM models: CHATGPT, DEEP SEEK and CHATAI. The results, as well as the comparison between them will be shown further in this paper.

4.3. **Step 3: Data Verification**

Since authors chose to use "Semi-supervised" based method, it was important to evaluate the results. That entailed checking if every text received at least one category, as well as if the results corresponded to the actual paper and index number provided. It was also necessary to analyze weather the results made sense for the study. At this time, authors decided not to influence in the categories provided by both the remaining LLMs, instead, they decided to compare the results between them.

4.4. **Step 4: LLMs Comparison**

The first LLM used for this study was CHATGPT, the second was recently launched DEEP SEEK and finally CHATAI. Aspects analyzed in the comparison were: 1) data display: how LLMs differ from the way they present the results and whether one interface provides a better way to read them; 2) response-time: how long it takes for each model to provide the results and weather one is faster than the other and 3) accuracy: how satisfactory the results were for the purpose intended and if one provided better results than the other.

The outputs were given a percentage of how many were distinct between models (completely different categories assigned to the same text); similar (if one or more categories

were the same, but not all of them); identical (if the output label was exactly the same for the text provided). Other aspects were not expected but also found relevant. The results of this comparison are described below.

5. Applications and Results

The main outcome of this study is the database of scientific papers regarding different initiatives that have been applied when building Smart Sustainable Cities, available in: https://docs.google.com/spreadsheets/d/1x6hOvB4SmToPkm9boJY3oZfwkaE5-JTaRcQ6XbEM9ns/edit?usp=sharingL. **Figure 1** shows how many papers were selected by year of publication.

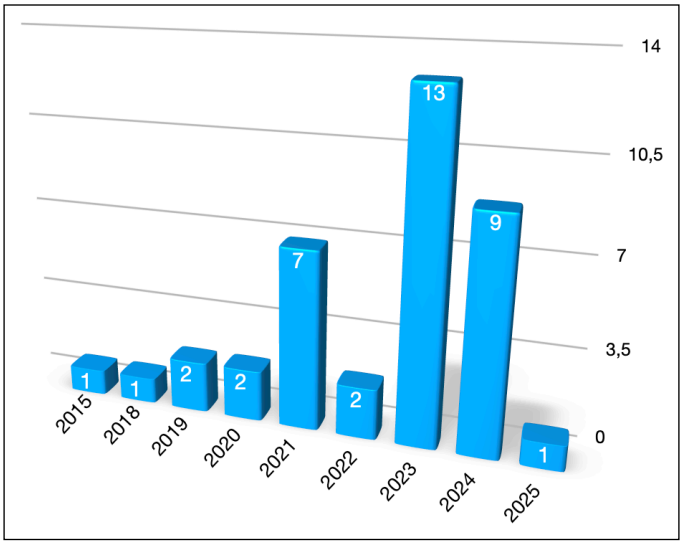

Figure 1: Number of scientific papers per year of publication. Source: elaborated by the authors.

However, the use of AI to perform this study is also valuable, as it sheds light on how LLMs can be used to catalise analysis of big data and better organize results, saving time and, in some cases, providing better outcomes. That is why results about how this study was conducted using AI tools are also relevant. Furthermore, as LLMs advance and new models are launched, it is important to understand how they differ from each other, so that researchers can chose the one which better suits their needs. Therefore, adding to the literature review, it is presented below the results of topic modeling and LLMs comparison.

5.1. Topic Modeling Using LLMs

The results of both CHATGPT and DEEP SEEK when assigning a topic to each paper are shown in the previous link. The papers are shown by their index number. To see which paper corresponds to each index number please also refer to the link.

It is important to highlight that CHATAI was also used in this study (as mentioned in the Method section of this paper), however, the results were not satisfactory. Firstly, CHATAI didn't acknowledge the index numbers on the abstracts provided, so it sorted every abstract as one text, separating not each paper, but each phrase within them in the categories. It also did not translated texts to English, maintaining the original language of each one, however mixing them when separating the categories. The result was a miscellaneous of phrases in English

and Portuguese put together into categories according to the theme they referred to. Therefore, this LLM will be used in the comparison with the others but its results will not be discussed in the topic modeling section.

5.2. **LLM Comparison**

Table 1 shows the most important aspects of the different LLMs used for this study and how each of them performed.

Table 1: Comparison between LLM models.

ASPECT	CHATGPT	DEEP SEEK	CHATAI
DATA DISPLAY	Did not accept the entire text, so the input was separated into three different entries. Output data organized by index, followed by the category assigned. Ex: Text 1 - Category: E-government.	Accepted the entire text as only one entry. Output data organized with the topic name as heading and the text (with its index) listed below. Ex: Else: Texts 4, 6, 7, etc.	Accepted the entire text in only one entry. Output not organized by paper or index but by phrases. Didn't standardized the language for the output.
RESPONSE-TIME	Less than 10 seconds per entry.	Less than 10 seconds (only one entry).	Almost 5 minutes.
ACCURACY	Very satisfactory. The results make sense and it didn't place any paper in the "else" category.	Satisfactory. Most of the papers were categorized as "else". Merged topics (such as Environment + Waste Management). Assigned a paper to "Leisure" when the text had the keyword Tourism in it, inferring a lack of accuracy.	Not satisfactory for the purposes of this study.
OTHER	Allows use without login however emphasizes the user can get better results when logged in. Allows for more accurate outputs in the paid version.	Don't allow its use without a login. Usage free of charge.	Only available to students with a valid login from a paying university.

Source: authors.

Finally, it is important to understand the difference in the outputs given by each model. **Figures 2 and 3** elucidate how similar the results were between CHATGPT and DEEP SEEK, as well as how they differed when assigning a category to each paper, respectively.

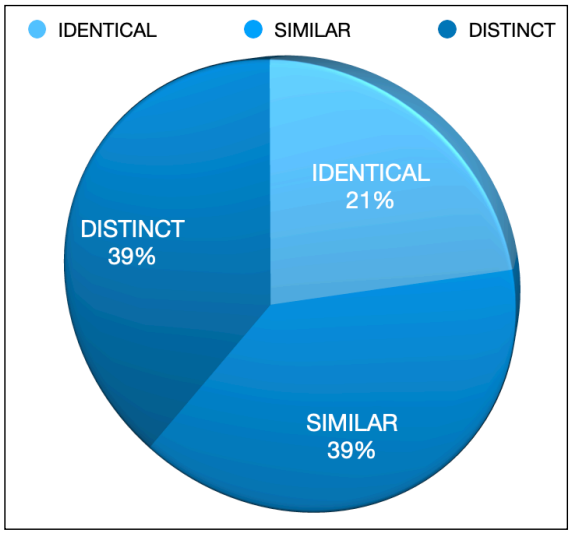

Figure 2: Percentage of similarity between LLM models. Source: elaborated by the authors.

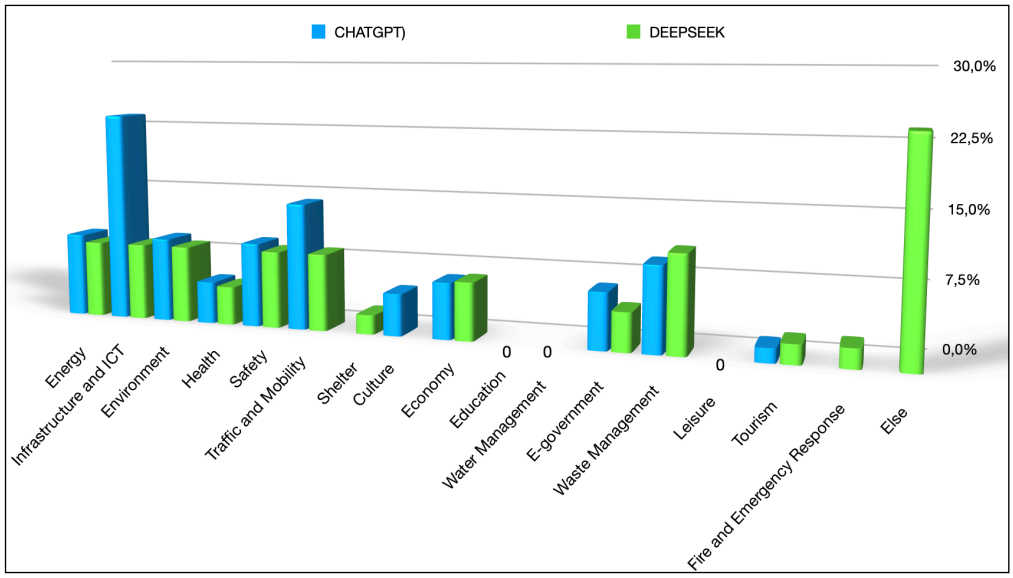

Figure 3: Output of LLM models by percentage of topic assignment. Source: elaborated by authors.

6. Analysis of Results and Discussions

In the 38 papers collected, most of them were published between the years of 2021 and 2024, with a significant drop in the year of 2022. It is important to remember that the world was undergoing through a global pandemic, starting on 2020 and officially ending in 2022. In the year which the pandemic started we can see a low rate of AI publications but in the next year a significant increase. That could be argued due to the amount of data the pandemic brought to light, as well as the advancements in technology that accompanied this period. Before year 2020, there was very little publications about the theme of this study, being the first one in the year of 2015. It can be observed, then, the use of AI in the context of Smart Sustainable cities is a relatively new subject, and it has a tendency of increasing the

discussion for the next years, which corroborates with the importance of works similar to this one.

The previous study used as base for the categories selection of this one (TEIXEIRA *et al*, 2022), had assigned a high priority level to the themes of energy, infrastructure and ICT, traffic and mobility, environment, safety and health. The literature review performed in this study shows that the themes in which AI is being used, in the context of Smart Sustainable Cities are very similar, as they ranked 23.8% (infrastructure and ICT); 14.3% (traffic and mobility); 9.5% (energy and environment), with the addition of safety and waste management (also 9.5%) and Health ranking slightly lower (4.8%), using the outputs of CHATGPT. That could indicate that all initiatives worldwide are leaning towards the same tendencies.

It is important to point out that, as the previous study, this one also found that themes such as Culture, Education, Leisure and Tourism are not being aimed as primary derivatives in most cases of urban planning. That can arise a concern of how technology (specially AI) can integrate those themes into urban planning moving forward, as they are part of what makes a city more sustainable and play an important role in improving quality of life.

In terms of using LLMs for topic modeling, CHATGPT proved to be the most suitable tool for this study specifically, as it provided outputs that were more accurate to the authors' expectations, specially considering the fact that DEEP SEEK categorized most of the papers as "else" instead of assigning one of the themes provided. It can also be observed that the categorization of topics provided by CHATGPT was more accurate. An example could be Index number 1, where CHATGPT categorized as "E-government" and DEEP SEEK categorized as "Safety". In that case, the paper talks about data privacy and management on public administration, which could be argued to fit better as E-government when analyzed.

Another feature that could be observed as a difference between the two models was when assigning more than one category. In this case, authors did not offer a limit to the LLMs as to how many categories each paper could be assigned to. However, CHATGPT "took the liberty" of assigning one, two or even three categories when identified to be correct. Although DEEP SEEK did the same in some cases, most of the time it categorized as "Else" when more than one category fit the paper's theme.

7. Final Considerations

The present study didn't dive deep into the possibilities of LLMs use when working with big data. Further applications could include the use of python language to enhance the analysis on a larger scale or even to extract the data straight from a .csv or .xls file. In a larger study, we intend to expand the analyzed papers referencing the ones mentioned in this study.

An argument mining analysis could also be performed in the papers analyzed, to better comprehend which of the AI initiatives on cities were more successful than others, narrowing even further the field for future researchers. Furthermore, we intend to apply few-shot mode of LLMs in order to improve the results.

Furthermore, the expansion of this study will be repeating the process of gathering papers on a larger scale, using programming to extract information on papers automatically from the

internet. That will increase exponentially the sample performed in this study, as the time spent gathering and analyzing data will be significantly less when performed by machine. This larger sample can allow further considerations on the subject and maybe even broaden the conclusions.

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