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Sectorization in water distribution networks: a systematic bibliographic review

Setorização em redes de distribuição de água: uma revisão bibliográfica sistemática

Sectorización en redes de distribución de agua: una revisión bibliográfica sistemática

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Abstract

Due to the current economic situation in the countries and the growing need to guarantee the sustainability of services, supply companies are developing techniques for the optimization of available resources. Among the several failures identified in water distribution systems, the high level of water losses stands out. This problem is being minimized by combining the sectorization of networks with pressure management. The sectorization consists of its division into smaller sectors (Measurement and Control Districts - DMC's), in order to reduce the complexity present in the management of the network, ensuring greater reliability and improving the useful life for the pipes and devices of the system. Thus, this research aims to systematically gather scientific knowledge about the sectorization applied in water distribution networks, considering published academic articles and three databases of great relevance in the scientific literature. The methodological approach of the present work was a systematic review of the literature on the subject. A total of 37 papers were systematically identified and reviewed, through which it was possible to identify the most relevant articles. The main methodologies applied to the sectorization process are extracted, the algorithms adopted and the main benefits resulting from the application of the sectioning of the network.
Keywords: Distribution; Networks; Sectorization.

Resumo

Devido à atual conjuntura econômica dos países e à crescente necessidade de garantir a sustentabilidade dos serviços, as empresas fornecedoras estão desenvolvendo técnicas para a otimização dos recursos disponíveis. Dentre as diversas falhas identificadas nos sistemas de distribuição de água, destaca-se o alto índice de perdas de água. Este problema está sendo minimizado pela combinação da setorização das redes com o gerenciamento de pressão. A setorização consiste na sua divisão em setores menores (Distritos de Medição e Controle - DMC's), de forma a reduzir a complexidade presente na gestão da rede, garantindo maior confiabilidade e melhorando a vida útil das tubulações e dispositivos do sistema. Assim, esta pesquisa visa reunir sistematicamente o conhecimento científico sobre a setorização aplicada em redes de distribuição de água, considerando artigos acadêmicos publicados e três bases de dados de grande relevância na literatura científica. A abordagem metodológica do presente trabalho foi uma revisão sistemática da literatura sobre o assunto. Um total de 37 artigos foram sistematicamente identificados e revisados, por meio dos quais foi possível identificar os artigos mais relevantes. São extraídas as principais metodologias aplicadas ao processo de setorização, os algoritmos adotados e os principais benefícios decorrentes da aplicação do seccionamento da rede.
Palavras-chave: Distribuição; Redes; Setorização.

Resumen
Debido a la situación económica actual de los países y la creciente necesidad de garantizar la sostenibilidad de los servicios, las empresas proveedoras están desarrollando técnicas para la optimización de los recursos disponibles. Entre las varias fallas identificadas en los sistemas de distribución de agua, se destaca el alto nivel de pérdidas de agua. Este problema se minimiza combinando la sectorización de las redes con la gestión de la presión. La sectorización consiste en su división en sectores más pequeños (Distritos de Medición y Control - DMC's), con el fin de reducir la complejidad presente en la gestión de la red, asegurando una mayor confiabilidad y mejorando la vida útil de las tuberías y dispositivos del sistema. Así, esta investigación tiene como objetivo recopilar sistemáticamente el conocimiento científico sobre la sectorización aplicada en las redes de distribución de agua, considerando artículos académicos publicados y tres bases de datos de gran relevancia en la literatura científica. El enfoque metodológico del presente trabajo fue una revisión sistemática de la literatura sobre el tema. Se identificaron y revisaron sistemáticamente un total de 37 artículos, a través de los cuales fue posible identificar los artículos más relevantes. Se extraen las principales metodologías aplicadas al proceso de sectorización, los algoritmos adoptados y los principales beneficios derivados de la aplicación del seccionamiento de la red.
Palabras clave: Distribución; Redes; Sectorización.

1. Introduction

The loss of water in the supply system is a topic of great importance because it is a problem of a world order. The water crisis, resulting from climate change and exponential population growth, coupled with current global trends in environmental protection and economic efficiency, highlights the importance of reducing levels of water loss. Being their control one of the biggest challenges for supply operators in the 21st century (Wang & Zhou, 2017) (Santi, 2018) (Melgarejo-Moreno, et al., 2019) (Yan, et al., 2019).

There is a great variation in the loss rates, since factors such as: country, region and age of the system, directly influence this indicator. In developed countries, very low values of 3% to 7% are found, as is the case in the Netherlands. Countries such as the USA and the United Kingdom have rates of 10% to 30%, however, there are reports that this percentage reaches 70% in some underdeveloped nations (Beuken, et al., 2008) (Puust, et al., 2010) (Santi, 2018).

Data from the Diagnosis of Water and Sewage Services, showed a slight increase in the loss rate in the Brazilian water distribution systems. The latest study released, presented data for the year 2017, where the country had an average loss rate equal to 38.5%, with a slight increase in relation to the 2016 diagnosis, which indicated a loss of treated water equal to 38, 3% (Brasil, 2019).

If it were possible to restrict these levels of losses to 15% (reference standard), the country would present a great reduction in the pressure on its water resources. Currently, about 6 billion m³ of treated water per year is lost, a volume sufficient to supply about 98 million people in one year, considering the average per capita consumption of 59.1 m³ (Brasil, 2019).

A water distribution system is the set of pipes, accessories, reservoirs and pumps that have the function of bringing water to consumers in sanitary conditions, with flow and pressure, that is, sufficient quality and quantity. Each network is unique and has its own characteristics such as local topography, water availability, rainfall and population growth; therefore, the dimension of the network and the complexity of its dimensioning are directly proportional quantities, which results in the challenge to Organs competent bodies (Porto, 2006) (Andrade, 2016).

As most of the components that make up these complex systems are buried, their construction, maintenance, operation and management require a high investment. Considered a crucial infrastructure component, water distribution networks are vital for urban development, with the control of distribution losses being the major challenge for supply utilities worldwide (Marques, et al., 2015) (Mala- Jetmarova, et al., 2018).

This challenge becomes even greater when faced with the problems commonly found in networks in operation, such as old and deteriorated installations, and inefficient loss management (Marques, et al., 2015) (Zhang, et al., 2019).

Increasing the efficiency and effectiveness of supply for a demand with the lowest cost, is considered a critical objective of operation and management by the supply concessionaires. Specifically, effectiveness requires the reduction of leaks and unprofitable water, being possible from the control of pressure, aiming at uniformity and sufficient quantity in the entire system (Mala- Jetmarova, et al., 2018).

The sectorization of water distribution networks is described as an established methodology used in operational control. The technique implies the definition of areas that can be partially isolated from the rest of the network.

The sectioning of a network, in small networks called measurement and control districts - DMC's, has been proposed as a strategy for the reduction of leaks, being carried out, from the installation of flow meters or valves in certain places, allowing the flow within each district to be monitored (Burrows, et al., 2000) (Morrison, et al., 2007) (Hajebi, et al., 2013) (Proctor & Hammes, 2015) (Campbell, et al., 2016) (Zhang, et al., 2019).

Most researchers agree, that sectioning the network into sectors (DMC 's) provides a number of benefits, such as: substantial reduction in water lost through active leakage; simplification of pressure management, by activating the pressure reducing valves - PRV; isolation of sectors, providing security to the system against events of accidental or criminal contamination; and potential for creating independent DMCs supplied from a single source, thus improving product quality (there is no combination of water from different sources) (Morrison, et al., 2007) (Di Nardo, et al., 2013) (Saldarriga, et al., 2019) (Di Nardo et al., 2014).

In the studies presented by Ilaya - Ayza et al. (2017) and Ciaponi et al. (2019), in addition to the benefits of sectorization for monitoring contamination events, the technique has shown great efficacy for the ideal positioning of flow meter valves.

However, despite the numerous advantages, the authors point out as a negative result, as a consequence of the reduction in the number of network connectivity and lowering of system pressure, the unpreparedness of the network in the face of emergency events, such as fire fighting and suspension of supply due to pipe breaks (Ilaya – Ayza, et al., 2017) (Ciaponi, et al., 2019).

Still being an additional concern, the deterioration of product quality (increase in the age of water) resulted in the reduction of available paths (Grayman, et al., 2009) (SCARPA, et al., 2016).

The task of dividing an original network into suitable sectors is a major challenge for supply utilities, mainly due to the intrinsic complexity of the network. In the past, before mathematics, this activity was carried out according to the limits of the municipalities, roads, number of inhabitants, economic level and location of reservoirs, totally disregarding the global perspectives (Morrison, et al., 2007) (Di Nardo, et al., 2013).

However, with the advent of mathematical models, hydraulic solvers have simplified the process by providing several approaches to optimize the generation of DMC's at the same time, while considering the constraints and operational objectives imposed (Di Nardo, et al., 2013) (Saldarriga, et al., 2019).

Currently, the sectioning of the network is a heuristic process controlling for two phases: grouping and optimization. In the grouping phase, DMCs are pre-formed based on network connectivity and topology. Performed through the implementation of several algorithms, aiming at the formation of viable sectors such as the least number of connections between them (Di Nardo, et al., 2013) (Saldarriga, et al., 2019).

Once this is done, the model is optimized for the rental of meters and valves, always aiming at maximizing the reliability of the network and minimizing economic costs (Di Nardo, et al., 2014).

2. Methodology

This research used RBS as the main method, as it allows other researchers to use the results obtained with greater reliability, due to the accuracy with which the steps are carried out. The systematic review is a methodology used to practice the bibliographic review in an organized way. Allowing a well elaborated conduction, in addition to making the basis of the work solid (Kitchenham, 2007) (Conforto, et al., 2011).

According to Kitchenham (2007), a RBS "is the way to identify, evaluate and interpret all available and relevant studies for a specific research question or thematic area, or phenomenon of interest". In addition, to state that all works that contribute to a systematic review are called primary studies. The systematic review being a secondary study, which allows a macro view of the primary studies.

A RBS can be classified as narrative or systematic, where the narrative is a simplified description of the studies and data on the subjects covered. Systematics, on the other hand, uses careful methods to guarantee scientific rigor and increase the veracity of the conclusions obtained (Cook, et al., 1997).

The research was developed in 14 stages, distributed in 3 parts. The first part, called as: entry - is the stage of the definitions.sions. Where we carry out theproblem determination, outlining the objectives proposeddefininwhich would be the strategy adopted searchs, the research sources that would be used, we determine the inclusion and exclusion criteria of the articles that would be reviewedcritfor the avalignment of the quality of the research and we define which the methods and tools adopted.

In the second part, the processing. It was performedresearch of articles in the databases adopted,the application of the inclusion and exclusion criteria, the quality action and selection the articles that followed for extraction.

In the third and last part, that of sawas created alerts in the databases, were made the registration and filing of aselected articles and carried out theíntesand and interpretation of results.

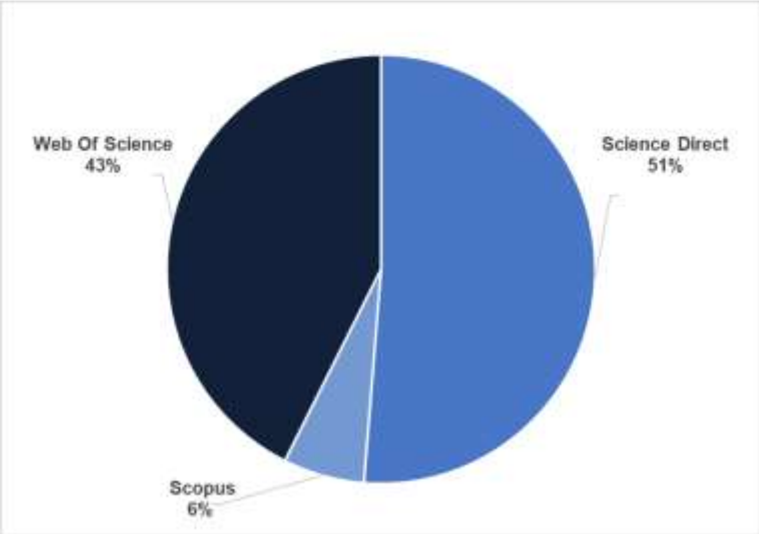
The methodological procedures used to outline and perform this mapping, was based on the guidelines of: Dybâ , Kampenes and Sjoberg (2005), Kitchenham et al. (2007), Travassos (2007) and Conforto, Amaral and Silva (2009). It is divided into three phases and subdivided into fourteen stages, as shown in Figure 1.

Figure 1- The figure illustrates the research development cycle in which fourteen steps were carried out, divided into three phases.

Source: Authors.

From primary searsches, 1.337 studies were returned.As shown in Figure 2, of the 1337 articles found: 51% (702) were extracted from Science Direct , 43% (551) from Web Of Science and 6% (84) from Scopus.

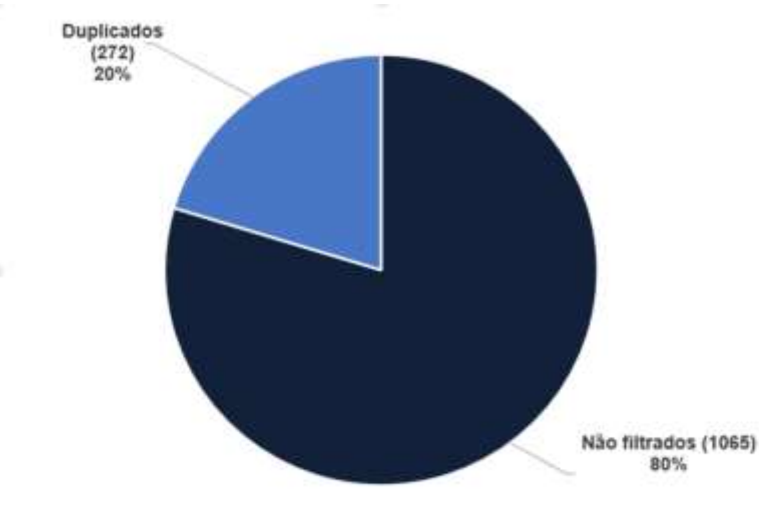
Figure 2 - Result of the search for articles.



Source: Authors.

Twenty-seven duplicate files were found, representing 20% of the results of the primary search, where they were excluded and the rest went on to further classification. as shown in Figure 3.

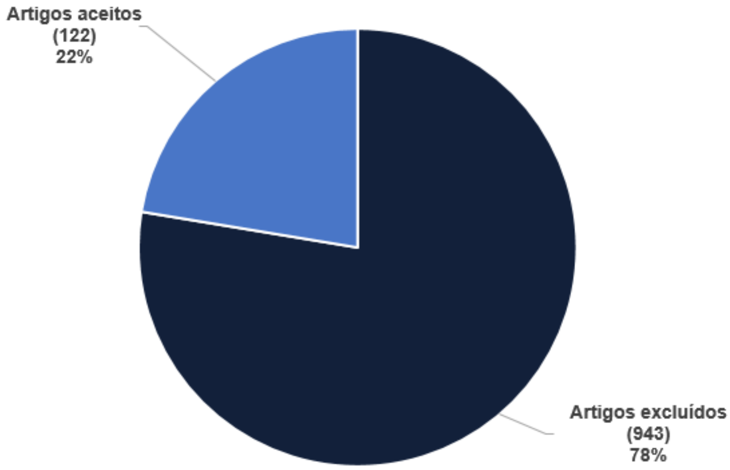
Figure 3 – Primary search results.



Source: Authors.

That done, the proposed reading filters 1 and 2 were executed and the inclusion and exclusion criteria were applied to the 1065 articles, resulting in the exclusion of 943 (78%) of them, as shown in Figure 4.

Figure 4 - Result of the reading filters and application of the inclusion and exclusion criteria.



Source: Authors.

The next step was the application of the reading filter 3 and quality assessment, in the 122 articles, where 37 studies were sent to phase 3 of the research.

3. Results and Discussion

3.1 Premissiom of the network sectorization process

The main objective of sectorization is the management and early detection of leaks present in a network. For this, the measurement of the minimum night flow is used, thus measuring the levels of losses within each sector, in addition to enabling the definition of the best location for the installation of the meters (Morrison, et al., 2007) (Grayman, et al., 2009).

One of the main factors that contributes to leaks is the pressure of the network. Loss reduction has been changing in terms of its approach, from passive (detection and repair) to proactive (heuristic procedures) (Morrison, et al., 2007) (Giugni, et al., 2008).

According to the work of Lambert (2012), the volume lost due to leaks is directly influenced by the increase or reduction in the network's operating pressure. The concept of sectorization was introduced to assist in proactive management, in invisible losses and in the detection of places where failures occur, based on the hydraulic characteristics of the network.

The scientific community agrees that the advantages generated by the partitioning of the network are greater than its disadvantages. The management of a network, with the application of sectorization, has shown highly satisfactory results , mainly in the reduction of leakage losses. By applying this technique, the UK supply company was able to reduce the number of leakage losses by around 85% (Farley, 2001) (Kunkel, 2003) (Morrison, et al., 2007) (Giugni, et al. , 2008) (Di Nardo, et al., 2013) (Di Nardo, et al., 2014) (Diao, et al., 2013) (Savic & Ferrari, 2014) (Di Nardo, et al., 2016) (Rajeswaran, et al., 2018).

Gomes et al. (2011), demonstrated that the sectioning of the network, allows the maintenance of stability in the pressure of the network, thus increasing the useful life of the system. The pressure reduction reduces the possibility of possible ruptures in the pipeline and, consequently, a reduction in real water losses.

The authors also propose, a method relating the minimum night flow with the pressure to predict water losses, in addition to estimating the reduction of energy consumption, through the invoiced water.

Huang et al. (2018) state that from the network sectorization, it is possible to quickly detect broken tubes, through the study of the uniformity of daily demand. They applied a supervised learning algorithm to improve the positive effect of real-time loss detection.

The works of Savic and Ferrari (2014 and 2015) and Lifshitz and Ostfeld (2018), illustrate the effectiveness of the implantation ofMeasurement and Control Districts - DMC's in water distribution networks, with respect to reducing the frequency of pipe breaks.

In the work of Lambert (2012), it was clear that the reduction in the frequency of pipe rupture, depends directly on the reduction in operating pressure obtained after sectioning. The study also revealed that controlling pressure reduces not only the frequency of pipe rupture, but also attenuation of leakage rates present in the system, thus extending the life of components and reducing water costs.

Still in this sense, in the study by Ferrari and Savic (2015), from the adoption of a sectorized network layout , it was possible to achieve a reduction of 53% to 60% in the frequency of rupture in the pipe and from 26% to 59% in the number of leaks, in addition to providing system protection, chemical counter-attacks or accidental events, with the closing of limit valves.

This isolation of sectors is still useful in the maintenance, replacement and repair of components, since with the closing of valves, there is the disconnection of the sector with the rest of the network (Di Nardo, et al., 2014).

According to Lifshitz and Ostfeld (2018), the combination of DMC's and Pressure Reducing Valves - VRP 's creates an approach called “knowledge and action” for the detection and management of leaks. The VRP 's reduce the excess pressure thus there is a reduction in potential leaks. However, without information about the possible location of the leak. DMCs, on the other hand, allow for quick identification of possible locations. In this way, this compilation creates an extremely effective tool for managing real losses.

The main disadvantages of sectorization are related to the deterioration of water quality. When compared to the original network, the sectorization results in a reduction of the network's resilience, mainly in the face of unexpected events.

Marchi et al. (2014) points to another disadvantage resulting from the sectorization process is the age of water, which is the time required to travel from the source to the final consumer. Influenced directly by the operating flow and length of the pipe, excessive age causes problems related to the quality of the product available.

In the work of UKWIP (2000), WRC (2000), Armand et al. (2018), used hydraulic variables to assess water quality and the probability of incidents. They state that the sectorization technique can compromise the quality of the water, with an increase in the average age of the water (mainly in dry tip type pipes) and sedimentation in the pipe, due to the low flow rate.

These studies go against the results obtained in the work of Grayman et al. (2009), Diao et al. (2013) and Di Nardo et al. (2015), where it was found that there were no significant changes in water quality after the sectioning of the network. This difference is most likely related to the quality limits adopted in the research, it is important to note that water quality is not addressed as a critical criterion for the elaboration of sectorized network plants. Thus, water age is not considered a project constraint (Di Nardo, 2015) (Saldarriga, 2019).

Salomons et al. (2017) and Javier et al. (2018), from the analysis of the water balance of a sectorized network, stated that the volume of water stored in the network is almost half of the daily consumption. That is, the water in the system was replaced twice a day, thus being a good indicator of water quality. They also performed a hydraulic simulation model to compare the behavior of the network before and after the sectorization, where no significant variations in the age of the water were observed.

Another disadvantage detected in some studies was the reduction in network redundancy. Due to the decrease in the availability of available paths (connection between source and consumption points). Result of the insertion of many valves and flow meters, for the isolation of the districts (Diao, et al., 2013) (Campbell, et al., 2014) (Di Nardo, et al., 2015).

Table 1 presents the summary of the main advantages and disadvantages of the application of sectorization.

Table 1 - Main advantages and disadvantages of DMC's.

Advantages	**Disadvantages**
Detection of ruptures and identification of leaks	Reduced network resilience against failures
Favoring managemen and control	Reduced operational flexibility
Favoring the control of operating pressure	Negative potential for water quality
Contamination protection	Security problems in peripheral areas in case of emergencies
Reduced maintenance and repair costs	High initial investment cost (deployment)
Characterization of the demand curve	Reduction in hydraulic redundancy

Source: Authors.

According to Farley (2001), several factors must be considered when designing sectorization projects, such as:

a) The maximum percentage of leaks allowed by the supply concessionaire;

b) The topography of the network and the number of consumption points, for each district;

c) Characteristics and topological taxonomy of the supply system;

d) Variations in demand and pressure in the network;

e) Number of flow meters and valves (pressure reducing and drawer type);

f) Water quality considerations.

The levels of economic efficiency of leaks for the districts are established based on criteria determined by the supply company itself, considering mainly: the situation of the network and volumes of existing losses.

From this, it is possible for the concessionaire to select the policy for the control of future leaks that is more heated. The size and numbers of sectors, as well as the staff required for the length of the policy adopted. (Farley, 2001)

Sectioning the network in small DMCs is the most efficient method for identifying leaks and failures in devices. In addition to being the configuration capable of maintaining, the volumes of losses at the lowest possible levels.

However, it is the arrangement where a high initial investment and higher operating cost is required, as a result of the number of flow meters and valves required. (Farley, 2001)

For the International Water Association - IWA, the size of the sectors is expressed by the number of consumption points, and should vary between 500 - 5000 connections to urban areas. For isolated DMCs, local factors and system characteristics, directly influence the determination of the size of the sectors (Huang, et al., 2018).

Although sectors with a lower number of connections require greater initial investment and maintenance costs, in sectors with a large number of connections, the identification of small disruptions and the location of leaks is an extremely difficult task (Farley, 2001) (Morrison, et al., 2007).

From the point of view of topological connectivity, a set of principles for complex networks was proposed by Giudicianni et al. (2018). Aiming to analyze the relationship between the values of the metrics and topological structures of the network, the optimization of the number of DMC's was performed with the aid of heuristics (reverse engineering).

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The study revealed that the number of sectors and the size of the network, basically follows a power law. Thus, the ideal number of sectors does not increase significantly with the size of the network, thus suggesting that, from the point of view of connectivity, the increase in the size of the network will have more effect on the size of the sectors than on the quantity (Giudicianni, et al., 2018).

Another factor that must be considered in the sectorization process stage is the number of sources for supplying the sectors. Due to the need to install flow meters for each source, which depends directly on the characteristic network (branched or meshed). Since a single sector can be powered by a single or multiple sources.

As suggested by Di Nardo et al. (2013), a technical rule for minimizing the number of meters is the installation of a single flow meter per sector, in addition to reducing costs, it will result in the simplification of the water balance.

The isolation of sectors is carried out by installing gate-type valves in the limit tubes, but the introduction of this category of device ends up creating “dry tips” alleys. In addition to reducing the paths available to consumption points, these “tips” can result in a deterioration in water quality (Farley , 2001).

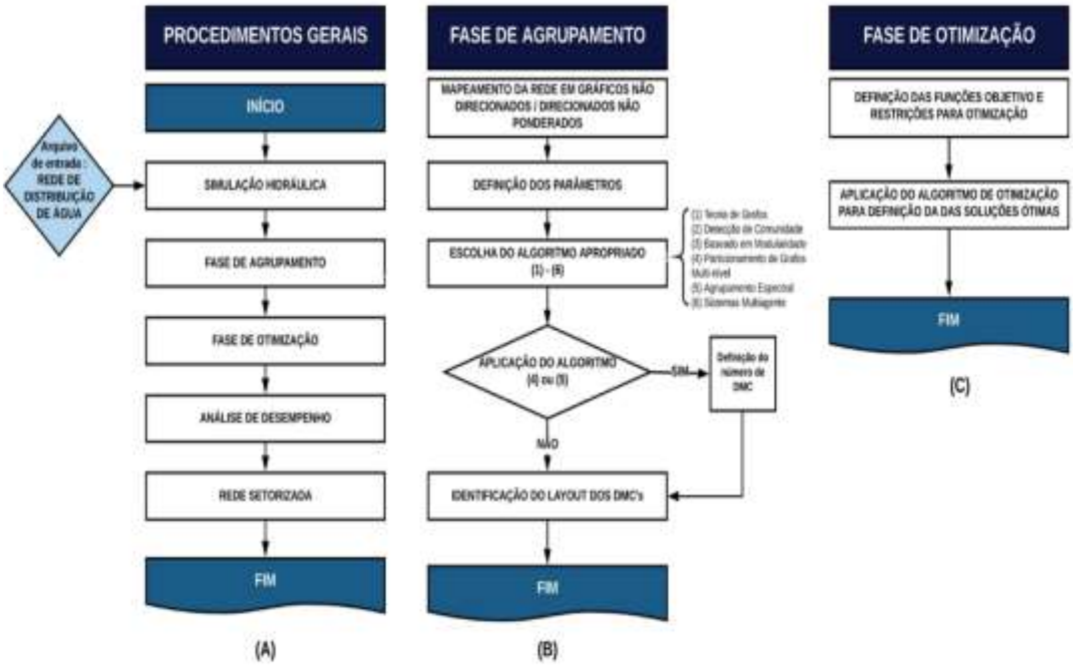
Thus, the optimization of the number and location of accessories, during the sectioning of the original network is extremely necessary to minimize costs and maximize operational benefits (Savic & Ferrari, 2014).

Defining the ideal sector configuration is a demanding task, given the many aspects of network performance that must be considered. Thus, sectorization is usually approached as a multi-objective optimization problem (Sela Perelman et al., 2015) (Giudicianni, et al., 2020).

Mainly due to the difficulty involved, only recently has this concept been addressed and explored in the scientific literature. Several models and approaches have been proposed aiming at creating the layout layout of ideal sectors.

Although the studies used algorithms from different categories, the sectioning process was generally obtained in two phases: clustering of the nodes and optimization , as shown in Figure 5 .

Figure 5- Water network partitioning steps: (a) General procedures, (b) steps for grouping, and (c) steps for optimization.



Source: Authors.

3.2 Grouping phase

The grouping step is the initial process, where the shape and dimensions of the sectors are projected from the topology of the network. The objective of this phase is to determine the ideal number of DMC's, aiming at uniformity in the number of consumption points by sector and minimizing the amount of limit tubes (cuts in the piping, for the installation of gate valves and flow meters).

The six algorithms that showed greater relevance and addressed in this research were: those based on graph theory (depth search - DFS and width search - BFS), community detection, modularity, multilevel partitioning, spectral grouping and multi-agent system.

3.3 Graph Theory

Most of the clustering algorithms in the scientific literature, aimed at sectioning networks, are directly related to graph theory. If the reader is not familiar with this branch of mathematics, it is advisable to read the works of Schaeffer (2007) and Song and Zhao (2008).

In the application of this class of algorithm, the topological structure of a network is plotted on a graph in an orderly or not, characterized by a pair of set G = (V, E). Where “V” is the set of vertices, representing the junctions, reservoirs and tanks. “E” is the set of edges, representing the pipes, valves and pumps of the system.

The BFS (width search) algorithm proposed by Pohl (1969), traces from a fixed “root” node, but unlike the DFS algorithm , the exploration of adjacent nodes is carried out by moving horizontally.

The DFS algorithm (in-depth search), on the other hand, is an algorithm based on graph theory and commonly used in this phase. This class of algorithm was proposed by Tarjan (1972), and has the ability to measure the connectivity of the elements present in a graph.

Everything starts with the choice of a “root” node in the network, where intuitively, the algorithm performs an exploration along each path until there are no more adjacent nodes, before going back (backtracking).

Tzatchkov et al. (2008), applied the DFS and BFS in sectorization projects in two Mexican cities (San Luis Río Colorado and Matamoros), where DFS , was used in the sectioning of the network in independent sectors (supplied by single sources) and for the identification of nodes belonging to the DMC's. BFS , on the other hand , was applied for the exploration of disconnected nodes from all available sources, aiming at the best “fit” in the sectors.

In the works of Perelman and Ostfeld (2011) and Liftshitz and Ostfeld (2018), the DFS algorithm was adopted for the identification of strongly connected nodes, that is, that presented paths in both directions. While the BFS algorithm , it was used for the classification of weakly connected nodes, where they presented only one path between the set of nodes. The results found were applied for two purposes: forecasting contaminants from a source and dissemination in a network.

Di Nardo et al. (2014), presented another proposal for the optimization of sectorization based on graph theory. In the methodology, a DFS algorithm was used in combination with a hierarchical approach developed by Di Battista et al. (1998), for the identification of independent sectors (isolated DMC 's), being disconnected from the rest of the network, through gate-type valves.

In the works by Campbell et al. (2016-a, 2016-b), a methodology for sectioning the network into two components was presented: a change network and a distribution network. To determine the trunk network, a BFS algorithm was used . Soon, defining the trunk network, it was disconnected and a community detection algorithm was applied in the distribution network, to define the best structural communities (sectors). The great notoriety present in these studies, was the fact that the main tubes (trunks) are not considered susceptible to sectioning. They functioned as an entrance for all sectors, thus ensuring great reliability for the network.

In a similar study, Alvisi and Franchini (2014) used a BFS algorithm to group possible nodes, in the formation of a predefined number of sectors.

Already Scarpa , Lobba and Becciu (2016), succeeded in isolating network, using the type of algorithm BFS in areas fed by a single source.

Gomes, Marques and Sousa (2012) presented a systematic way of sectioning networks, using the Floyd- Warshall algorithm and defining criteria (tube length, number of connections per sector). In the study, they also made a comparison with BFS algorithm. Where class of algorithm, it presented superior results, because, in addition to identifying the shortest path between the sources and the nodes, it pointed out which was the best route. The algorithm was adjusted and replicated until the number of DMCs and all restrictions imposed by the user were met.

3.4 Community Detection

The community detection algorithms are a hierarchical approach of ascending order, derived from the graph theory, being considered a class of recent algorithm. A community is understood as a group of vertices that have common properties within a network. If the reader is not familiar with this branch of mathematics, it is advisable to read the works of Newman and Girvan (2004) and Clauset , Newman and Moore (2004).

Diao, Zhou and Rauch (2013) were the first to use the community detection algorithm in the grouping phase, for the automatic creation of boundaries between DMC's. In the authors' work, a network was transformed into an undirected graph and the detection algorithm was applied.

In the work of Campbell et al. (2014), instead of identifying communities (nodes that have similarity), proposed a procedure, where the power lines (main piping) were not included in the sectorization schemes, with the sectors being recognized through the “intermediation” of the edges, by the flow analysis and the diameter of the pipe.

In the research by Brentan et al. (2017, 2018), the authors proposed a methodology in which the community detection algorithm was applied, in the node grouping phase, adopting technical factors such as: demand and pipe length, for the creation of different scenarios of the sectorized system.

3.5 Community Detection

Widely used in software development and solving complex problems. Modularity is understood as the ability to divide a large system into independent parts (modules). If the reader is not familiar with this branch of mathematics, it is advisable to read the works of Parnas (1972) and Mernik and Umer (2005).

Giustolisi and Ridolfi (2014) developed a methodology for partitioning networks, based on modularity, where the hydraulic properties of the network were combined, minimizing the number of cuts required for sectioning. However, the study showed inconsistent results, especially when applied to small networks.

Still in 2014, the same authors presented another study, where they mitigated the inconsistencies obtained in the previous study, based on corrections in the programming of the algorithm developed and adopted.

Ciaponi , Murari and Todeschini (2016), presented a methodology in which an algorithm based on modularity was adopted, but with a different approach. They combined convenient practices and criteria, such as: increasing the number of connections and reducing the operating pressure.

In the proposal presented by Simone, Giustolisi and Laucelli (2016), the sectorization of the network was carried out, based on a spatial distribution of the network followed by an assessment of the ideal number of necessary accessories, always aiming at uniformity between the modules (sectors).

Laucelli et al. (2017) advanced in this sense, when developing a methodology for grouping nodes, where the objective functions of the developed algorithm were: maximizing modularity (uniformity), minimizing the number of cuts and minimizing the amount of necessary accessories.

In the work of Zhang et al. (2017), a proposal was developed with hybrid procedures: combining modularity and community detection algorithms for grouping nodes, thus improving the results obtained by classical modularity. In addition to adopting, the theory of random walk for the identification with better precision of the nodes with greater similarity. Able to perform the grouping automatically.

3.6 Multilevel Partitioning

Multilevel partitioning is also an approach based on an analogy to graph theory, where for partitioning a graph, parallel computing is adopted. Always presenting the following objectives: allocation of workloads between processors, minimizing communication between them and equal distribution of computational load. If the reader is not familiar with this branch of mathematics, it is advisable to read the work of Karypis and Kumar (1998).

Sempewo , Pathirana and Vairavamoorthy (2009), developed a methodology for analyzing the spatiality of the distribution network and creating sectors in an automated way. Based on the balance of pipe length and demand in the sectors, using a computational tool for multilevel partitioning (Multilevel recursive bisection - MLRB).

In the work of Di Nardo et al. (2013, 2016, 2017 a, b) software developed by the authors themselves, adapted from the MLRB, the Smart Water Management Platform - SWAMP, where in addition to the determination of sectors in an automated way, partitioning was carried out in an “intelligent” way.

Sela Perelman et al. (2015), presented a study where they were applied to three techniques derived from the theory of graphs, in a real network (Singapore), in order to verify the performance of each one. The authors concluded that in addition to the advantages (assigning weights to nodes and tubes), this methodology has greater computational efficiency. Being able to allocate evenly, all the processes involved, resulting in a reduction in the exchange of information volume.

Alvisi (2015) proposed a procedure for automatic sectorization of the network using a combination of multilevel partitioning and hydraulic simulation. Unlike the traditional approach, it was possible in addition to the simultaneous allocation of nodes, within a certain number of sectors. The identification of the best location for flow meters and valves in the network.

3.7 Spectral Grouping

The spectral grouping is a mathematical approach, where the characteristics of the graphs are combined, with linear algebra and graph theory, to determine the eigenvalue and eigenvector properties.

The spectral grouping uses a spectrum in eigenvectors of an adjacent matrix (one of the ways to represent a graph), for the realization of the grouping of nodes.

This spectrum category has been adopted in several areas in the last decade, especially in computer science, bioinformatics and data analysis. Recently, this technique is being applied in the management of water distribution networks, mainly for the definition of the ideal configuration of the DMCs and preliminary analysis of the vulnerability and robustness of the network.

In the work of Di Nardo et al. (2017), the definition of the ideal DMC's layout for a real network, was carried out considering the geometric characteristics of the networks (connectivity) and hydraulic properties of the pipe (diameter, length, conductance and flow) through weight-adjacency matrices, result in a range of possible configurations.

The following year, in the work of Di nardo et al. (2018), the graph spectral technique - GST was applied , where an analysis of the network topology was performed, providing a set of tools for the assessment of current performance and possible expansion of the networks.

The authors also pointed out that with GST , it is possible to perform crucial tasks for the management of a supply system. Providing a structure, which allows the identification of the best nodes for the implantation of valves and sensors. Even, determine which nodes are most relevant to the network.

Liu and Han (2018) presented a strategy for automatic sectorization of networks, based on spectral grouping and graph theory. A spectral algorithm was used to determine the clustering of the nodes. Based on simulation of the steady state network considering the peak hour demand.

The same line of study was later approached by Zevnik , Kramar and Kozelj (2018, 2019) comparing two known spectral methods (proportion cut and normalized cut).

3.8 Multiagent Systems

The use of a Multiagent System - SMA is justified when the effort of two or more agents is required to solve a certain objective. An SMA can be defined as a network of problem solvers that operate simultaneously, to solve problems that are beyond the individual capacity.

If the reader is not familiar with this branch of mathematics, it is advisable to read the works of Brdshaw (1997), Jennings (1998) and Silveira (2000).

A water distribution network is considered a complex and dynamic system, where it comprises several elements (physical devices) with different objectives, actions and information. A small change in the behavior of one of these elements results in a change in the entire system. Thus, a water distribution network has a strong resemblance to an SMA .

The SMA has been successfully applied to problems related to the heterogeneity in the field of water, proving to be highly efficient in optimizing the control of water systems, pollution diagnostics, improving water quality and management demand.

Izquierdo et al. (2009) were the first to develop a software environment for the application of sectorization in water distribution networks using a multi - agent approach . They proposed a method, where knots and tubes were considered to be agents. Considered as a premise and basis for several other studies that replicated this technique.

Herrera et al. (2010) presented a study in which a sectorized network layout was proposed, where agents (nodes and tubes) were grouped by elicitation (exclusion), connecting nodes adjacent to certain points of origin and verifying the likelihood of presenting similarity between sectors proposed.

Years later, Herrera et al. (2012) present another study with a difference in the approach of the problem, in the previous study, the dispositions of the sectors were defined from the points determined as origin. In this research, the sectorization started to be done according to the geographic grouping of the network, changing the limit tubes, aiming at a better hydraulic performance.

Hajebi et al. (2013) presented a methodology for sectorization, from the combination of grouping by k- means and SMA. The grouping of k- means graphs was used to divide the network topology and SMA in the analysis of the proposed configuration, according to the hydraulic restrictions adopted.

3.9 Optimization Phase

Immediately after the formation of sectors from the grouping phase, network optimization is necessary. Stage where the validation of the positioning and determination of the quantity of necessary accessories takes place, for a reliable sectorized network.

Many heuristic algorithms and procedures have been proposed to find the ideal solution, aiming mainly at the optimization of hydraulic performance and efficiency in reducing leaks. It also works as a support tool for the decision making of the concessionaires. Presenting, the best trade-offs between cost of implantation versus hydraulic benefit indicators.

Most research points out, in order to obtain a sectorized network with lower implantation cost, the need to reduce the number of flow meters, since the cost of this category of accessories is much higher than the valves of the drawer type.

In addition, the placement of these accessories in the network has a significant effect on the properties of the network, such as: hydraulic performance, resilience index, leakage rate and water quality.

Thus, sectorization should be seen whenever possible, as a multi-objective optimization problem, in order to maximize the benefits generated by its implementation.

3.10 Single-Objective Optimization

Mainly for the simplification of computational demands, some hypotheses or heuristic processes have been proposed for simplification. From a multiobjective problem, to a single goal.

Although, the objective functions and restrictions differ in the different studies, all aimed mainly at achieving the best performance of the network possible after the sectorization process.

Di Nardo et al. (2011,2013, 2014-a, 2014-b, 2015, 2016-a, 2018), adopted as an objective function the maintenance of hydraulic performance with the lowest level of dissipated power, consequently, maximization of the nodal potential. To deal with the problem, the analysis between implementation costs versus hydraulic benefit indicators.

Shao et al. (2019), proposed a function where the double objective problem (hydraulic performance and cost) were converted into a single objective, considering the master-subordinate relationship of the objective functions, resulting in an improvement in computational efficiency.

Changes in the flow of operation, caused by faults in the piping can result in large losses of energy and pressure in the nodes. In the worst case, in failure situations, a network must be able to supply sufficient energy to supply all connections belonging to the system in minimum conditions.

This approach was presented in the work of Todini (2000), where the author assessed the resilience of a system in cases of failure.

Based on this approach category, several other studies were presented: Campbell et al. (2014), Alvisi and Franchini (2014), Alvisi (2015) and Giudicianni et al. (2020), where they used the index of resilience as an objective function.

Gomes, Marques and Sousa (2013) aiming at costs, proposed an optimization model based on the various options available in engineering to reduce the total cost. Simulating the behavior of the network, in different future scenarios, changing factors such as: demands and infrastructure degradation.

A similar study, in addition to considering future scenarios of demand and infrastructure degradation, also adopts economic and energy criteria. It was the research Di Nardo et al. (2017).

In the work of Creaco and Haidar (2019), the authors used linear programming, to optimize the settings of the control valves, aiming at the compensation between costs, uniformity of demand and leaks in the sectors.

To solve the optimization problems mentioned above, genetic algorithms - GA, were widely used (all studies by Di Nardo et al .).

Shao et al. (2019), modified the crossing and mutation mechanisms of a GA to obtain an agile sectorized network layout. In the work of Gomes et al. (2012-a, 2012-be 2013), the authors adopted a simulated annealing algorithm to solve the proposed problem.

3.11 Multiobjective optimization

Zhang et al. (2017), present a multi-objective optimization approach for sectorization, in which three objective functions were adopted: number of limit tubes, pressure uniformity and water age.

Years later, another study by Zhang et al. (2019) suggested a multi-objective optimization for sectorization layouts , but this time, fully amenable to implementation. At the same time: pressure stability, water quality and transformation costs (implantation).

De Paola et al. (2014) presented in their work a multiobjective function to deal with the total cost of sectorization, relating the costs caused by losses and the cost of electricity generated by the operation of pumps.

In the work by Hajebi et al. (2014), two sets of objectives were considered for the sectorization task, the structural and hydraulic objective. For the structural objective, the minimum cut size and diameter of the limit tube were determined. As for the hydraulic objective, after sectioning, four objectives were adopted: minimizing the average pressure of the nodes, dissipated power and maximizing the resilience of the network.

Bretan et al. (2017), presented a methodology, in which a multilevel optimization concept was adopted to reduce the complexity present in the sectorization process. In this approach, two groups of objectives were minimized. The first, corresponding to structural costs (installation of accessories), and the second to hydraulic performance (minimum and maximum pressure, and resilience index).

Galdieiro et al. (2017) present a decision support tool for engineering, based on two objective functions. Aiming at a more comprehensive methodology of network sectorization processes. The first refers to the total cost, including: costs of implementation and related to losses, with hydraulic performance (resilience index).

Recently, Giudicianni et al. (2020), presented a heuristic structure for the dynamic partitioning of a network. Using multiobjective functions to serve different purposes related to costs, water quality and energy savings. Considered a bold methodology, because, in addition to being sectorized, the network would become self-sustainable. From installations of micro hydroelectric stations along the network.

For the interaction between different algorithms and multiobjective functions, Di Nardo (2016) developed a software called SWANP. Enrolled in a Pytohn environment, it is considered an effective support tool, capable of providing engineering, different layout solutions.

Many optimization algorithms have been applied to solve multiobjective problems in water distribution systems. The NSGA-II genetic algorithm is the most widely applied, as it makes available in front of Pareto, a cloud containing a set of ideal solutions.

If the reader is not familiar with the genetic algorithms, it is advisable to read the work of Goldberg and Holland (1988).

3.12 Iterative approach optimization

An interactive method, is a mathematical procedure in which a viable solution is obtained from an initial estimate, generating a possible sequence of solutions. The result is considered convergent and satisfactory, when the set of solutions obtained meets the adopted criteria.

Diao, Zhou and Rauch (2013), obtained the optimization of the network, through an interactive approach, where the minimum necessary operating pressure was adopted as a restriction criterion.

Liu and Han (2018) proposed an interactive method, based on a heuristic procedure. For the determination of the best location of the flow meters, where the criterion adopted, was the shortest path from the source.

3.13 Evaluation of sectorization performance

To gauge how much the sector impacts on the hydraulic behavior of the network, performance indexes - ID's are used.

Able to quantify the benefits and harms resulting from those of the process. Most studies apply an index to validate and verify the effectiveness of the proposed method.

The most used indices are: resilience, pressure, uniformity, water quality, fire protection.

The resilience index is often used to evaluate the performance of the network, from a comparison of hydraulic behavior, before and after the sectioning process. Most of the studies pointed out that this index was not significantly affected by the sectorization process. This fact was widely discussed in the work of Herrera , Abraham and Stoianov (2016).

If, on the one hand, a resilience index is adopted to assess the overall performance of the network, the statistical indices allow an assessment of the quality of the service delivered to customers.

These indexes were explored in the work of Di Nardo et al. (2015), where indicators were developed and analyzed to assess the excess pressure and the real pressure deficit of a sectorized network, compared with the design pressure.

Another indicator of great relevance is the one referring to the quality of the water, which, because it is influenced by the topology of the network, flow velocity and length of the pipe, suffers a high impact due to the sectioning process.

The age of the water is mainly affected, with regard to the levels of residual chlorine. Where low values, induce bacterial growth, in the highest standards, indicate a worse performance (higher cost of treatment).

The works of Grayman , Murray and Savic (2009) and Di Nardo et al. (2015), presented as a result, a sectorization process, with no major impact on water age. Despite generating significant variations in some specific nodes , due to the insertion of shut-off valves. When the whole set was analyzed, the change was not considered significant.

Although this category of accessories (valves), is widely used in the network sectorization process, presenting a high degradation capacity in the water age, it can provide security for the network, against the spread of contaminants in the case of malicious attacks.

Di Nardo et al. (2013, 2015) present a research where a cyanide attack was carried out, demonstrating the effectiveness of this device, preserving a large part of the network.

Still in line with the assessment of the quality of the service provided, Grayman Murray and Savic (2009), proposed an index to quantify the potential impacts of contaminants on the population's health.

The pressure uniformity index was addressed in the studies by Araque and Saldarriga (2005), Alvisi and Franchini (2014), Brentan et al. (2018), Liu and Han (2018). Pressure uniformity is suggested as a guarantee that all nodes belonging to a sector have similar pressure and flow patterns. The lower the value of this index, the better the performance of the system.

Liu and Han (2018) proposed a decision-making framework for the determination of DMC's, functional and efficient, from the quantification of various indices (uniformity, modularity and resilience) evaluating the benefits resulting from the sectioning of the network comparing cost-benefit .

Another tool to support decision-making was presented by Ferrari and Savic (2015), evidencing the savings that sectorization can provide, for the supply companies, considering three factors: reduction of leaks, ruptures in the pipeline and pressure, compared with the original network. The authors state that the reduction in pressure across the network was the main factor that led to the reduction of leaks and ruptures.

To verify the behavior of the sectorized network in the face of emergencies, in the works of Grayman , Murrary and Savic (2009) and Di Nardo et al. (2015), fire protection indices were developed and presented, based mainly on the number of nodes with a pressure lower than the required pressure projected for this category of event. The results indicated that despite some negative pressure values, most of the nodes were an acceptable pressure.

4. Conclusion

This research aimed at a panoramic view of the relevant studies, related to the sectorization of water distribution networks. Where for the execution of the sectioning in an optimized way, it is necessary a satisfactory performance in the two understood phases.

In the first stage, the grouping phase, the sectors are formed and the boundary tubes and main tubing (trunk) are defined. The algorithms that have been shown to be more efficient and, consequently, more used, are based on graph theory.

It can be said that this is the crucial stage of the network sectorization process. Various algorithms and tools have been developed and improved for the application of the sectioning technique in large-scale networks, where manual partitioning is an arduous and practically impossible task.

Various engineering aspects, such as the adoption of weights for modulating network characteristics, have been incorporated into this process, in order to obtain realistic results.

Thus, an increasing number of extensions for the grouping algorithms applied in weighted networks are being presented, as well as, new methods for the graphic grouping.

The second step, optimization, is the identification and rental of the necessary accessories (valves and flow meters) to meet the proposed operational restrictions. Demanding the application of optimization algorithms or heuristic procedures, the most applied being genetic algorithms, but specifically (NSGA-II), with a multiobjective approach.

Being the objectives of greater impact and consequently more adopted: the minimization of the transformation costs, energy use and maximization of the hydraulic reliability.

The improvements and innovations in the sectorization process presented so far, are focused on the way in which the problem is addressed. The most common proposals today are those aimed at the automated creation of sectors. Although there are different approaches to the identification of sectors in water distribution networks, few studies address the determination of an ideal number of sectors for a given network.

With regard to the optimization phase, studies are still lacking to assess the behavior of pumps and reservoirs in sectorized networks. Thus, it is concluded that the technique of sectorization of networks, despite already presenting extremely satisfactory results, still presents a large number of unknowns and gaps to be answered in future works .

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