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Data Integration Framework to Collect Data from OT/IT Systems

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Abstract: Industry 4.0 and industrial data processing, due to its inherent possibilities, is gaining more and more emphasis in production companies these days. In a corporate environment, the age of equipment is extremely heterogeneous, in addition to state-of-the-art equipment, legacy systems can also be found in the machine park, which do not have appropriate communication protocols. Also, with the increase in the number of data sources, the management of data is becoming more and more challenging. Not only the operational technology, but also the connection of different IT systems and the extraction of data pose challenges. The different data processing use-cases using partly or entirely the same data sources, so it is necessary to extract and transmit the data to the target systems in a standard way, and avoiding an increase in the number of point-to-point interfaces. In this work we present a possible framework, to solve the above mentioned problems in industrial environment, with the introduction of standardized naming conventions, OT/IT gateways, data integration and distribution layers.

Keywords: Data acquisition; data integration; industry 4.0; MQTT; operational technology

I. INTRODUCTION

Industrial data acquisition involves collecting and analyzing data from various industrial sources such as sensors and machines to improve productivity, efficiency, and safety. Predictive maintenance, lifetime prediction and intelligent quality assurance systems represent an enormous opportunity for manufacturing companies. Significant financial savings can be achieved by reducing maintenance and scrap costs and increasing quality. Advanced technologies and methods are available to clean, process and analyze data, but the data must first be collected.

The data collection methods can include direct connections between sensors and data acquisition systems, as well as wireless or wired communication protocols [1]. Data can also be collected and processed using edge computing technologies, where data is processed at the edge of the network, closer to the data source [2]. Industrial data acquisition methods also utilize data storage systems, such as databases and data lakes, to store and manage large volumes of data [3]. By implementing effective industrial data acquisition methods, organizations can improve their ability to monitor and optimize industrial processes in real-time. Message brokers such as Apache Kafka [4] and RabbitMQ [5] are commonly used in industrial data acquisition due to their high throughput and low latency. These message brokers provide features such as message persistence, fault tolerance, and scalability, which are important for handling large volumes of data in industrial settings. By using message brokers in industrial data acquisition, organizations can improve their ability to monitor and optimize industrial processes in real-time[6].

Besides the challenges of data acquisition methods, the age of equipment is extremely heterogeneous. The life cycle of a product can reach up to 10-15 years, and this often means the age of the production line as well. In addition to state-of-the-art equipment, the machine park also includes legacy systems that do not have the necessary communication capabilities for large-scale data collection. One of the challenges is extracting data from legacy systems and converting it into the appropriate form described by data governance.

With the increasing number of data sources the identification of the data and their sources becomes challenging. The age of the machine park also has an impact on the identification of machines. As a result of poor change tracking of the naming of machines, their physical identification and the identification of the machines in the IT system can differ. On the other hand, the ID of a specific machine can be different and ambiguous in different IT systems. These factors have a great influence on the identification and assignment of the related data sources and datasets. Industrial equipment naming conventions provide a standardized approach for naming equipment in an organization. One method is the use of a code or numbering system that identifies equipment by type, function, and location [7]. Another method is to use acronyms or abbreviations that have meaning for members of a group or organization [8]. A third method is the use of a descriptive name that is based on the function of the equipment [9]. A combination of these methods can also be used to provide a unique and standardized name for equipment [10]. The selection of a naming convention method depends on the specific needs of the organization and the industry it operates in.

Another relevant aspect of the data collection is the manageability of interfaces of the IT systems and the network performance. Different types of datasets are stored in different IT systems, like part tracking systems, machine and process data systems, and quality databases. The different data processing use-cases use partly or entirely the same data sources. If we use separate interface between every system and use-case, the number of connections can grow rapidly, according to equations (1), where n is the number of nodes.

$$n\frac{(n-1)}{2} \tag{1}$$

To avoid the point-to-point interfaces between the separate data processor applications and the different IT systems, the data extraction and distribution need to be standardized. In the next section we describe the architecture and the rules of the data integration framework.

II. Data Integration Framework

The data integration framework is a set of architectural components and rules which propose a solution to the collection, identification and distribution of data. The main parts of the architecture (**Fig. 1.**) are:

- Controller level
- Gateway level
- Distribution level
- Application level

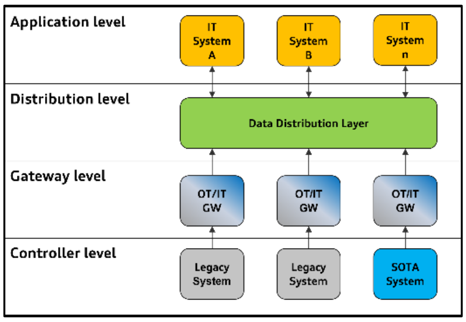

Figure 1. *Data integration framework architecture*

The communication of the components can be bidirectional, but this is not mandatory.

The controller level contains the source systems like programmable logic controllers (PLCs), numerical control units (NCUs), Internet of Things (IoT) capable devices and other automation hardware. The state-of-the-art (SOTA) components are capable to communicate event driven, with higher level protocols like MQTT, but in some cases polling and transformation of the messages are necessary.

The function of the gateway level is to physically separate the operation technology network from the corporate network. Besides security, this level can have other responsibilities, like buffering the incoming messages in a case of network failure, or polling the legacy devices and hosting data acquisition agents and translation of the protocols.

The goal of the distribution layer is to forward the messages to the target systems. One advantage of this architecture, that the source system does not need to know the receiver, it has only send the message to the distribution service and it forwards the message to the designated system, which is subscribed to the data source.

The application level contains the legacy IT systems and other use-cases, which processes the data from the controller level and related IT systems. These components communicates through the distribution layer, this way the point-to-point interfaces between system can be avoided and the

Table 1. *Standardised naming convention*

Global ID	*Business Unit ID*	*Domain*	*Unit*	*Subunit*	*Component*
01	P	Domain A	MG0012	MA001	MS01
02	L	Domain B	TU0123		
01	F	Domain C	AE0200	CP012	SS01

data can be used by other systems as well, no need the duplicate the data through distinct interfaces.

The architecture alone cannot guarantee the reliable and manageable message flow between the components, further rules are needed to manage the communication. These rules are defined by the data governance and are the following:

- Standardized naming convention of data sources
- Standardized message structures
- Distinct channels for predefined message types

1. Standardized Naming Convention

The source of the data needs to be clearly identified[11][12] to forward the information to the corresponding data processor and to connect the related data. To achieve this behavior, we introduced a standardized naming convention of the source components. The nomination of the components not only identifies the source, but contains additional information like the location, hierarchy and type of the unit. The naming convention capable to identify other assets too, like buildings, halls, facility equipment, logistical vehicles, storages. The asset management is not scope of this work.

The coding consists of six level arranged to tree structure (**Fig. 2.**), each level identifies a separate entity of the hierarchy. The usage of every level is not mandatory, but the notation must follow the top-down structure, starting with the global ID. **Table 1.** shows the structure of the standardized naming convention and three examples (top-down, read left to right):

- Measuring system 1 of Machine 1 in Machine Group 12 of Domain A, Business Unit: Production, Factory: 01.
- Tow unit 123 of Domain B, Business Unit: Logistics, Factory: 02.
- Speed sensor 1 of Compressor 12 in Air Engineering 200 of Domain C, Business Unit: Facility Management, Factory: 01.

The notation of components is standardized in a code library. The delimiter of the sections is arbitrary, depends on the use-case or the system, which processes the data.

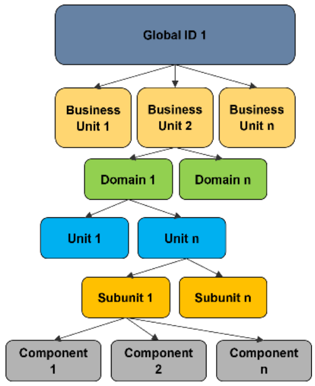

Figure 2. *Tree structure of the standardized naming convention*

2. Standardized Message Structure

In addition to the standard naming convention, a standard message structure is strongly recommended. The uniform structure of the messages makes the data acquisition and the message protocols independent, allows the exchange of the underlying transmission protocol without disrupting the data flow, and makes it easier to manage the collected data.

To connect to the data distribution framework, the participating system only have to utilize the standardized message structure. If the source system meet the requirements of the message structure, the technology of the data collection and the transmission protocol can be arbitrary.

The standardized message structure is based on the JavaScript Object Notation [13] (JSON) format. JSON is a lightweight, self-describing textual object. The textual format makes it possible to interpret the data in a programming language independent way, therefore it is used to store or send data between computers or programs.

The mandatory content of all of the messages are the source identification, the message timestamp, the message version and the counter of lost messages. The related dataset are assigned to predefined channels or topics, thus all other content depends of the message type. An example of the JSON message shown on **Fig. 3**.

Table 2. *The use of standardised naming convention in message topics*

Topic subscription	*Meaning*
01/P/#	Subscription to all elements and topics in Factory 1, Business Unit Production
01/P/DomainA/#/#/Energy	Subscription to Energy topic, all units and subunits in Factory 1, Business Unit Production, Domain A

```
{
„SourceID": „01/P/DomainA/MG0012/MA001",
„TopicRelatedData1": „Data1",
„TopicRelatedData2": „Data2",
„TopicRelatedData3": 123,
…,
„MessageTimeStamp": "2022-12-11T22:54:00.000+01:00",
„MessageVersion": „Example_01.0",
"LostMessages":"0"
}
```


Figure 3*. An example of the JSON message*

Another good practice is to organize the message topics in a way, which utilize the standardized naming convention. With this method all hierarchy level of the naming convention and all message types are accessible. The selection of multiple elements is possible with wildcards (#). **Table 2.** shows different topic subscriptions and their meanings.

3. Data Distribution Layer

In order to transfer the collected data between the source and the destination, a data distribution layer is needed. The industrial use-cases requires scalable, loosely coupled and dynamic network topology, thus the publish–subscribe (pub-sub) messaging pattern [14][15] is used.

In pub-sub messaging, the publisher (source) does not need to know, who is the subscriber (destination), it only has to publish the messages to the data distributions layer in to the related topic, then the service forwards the messages to the corresponding subscribers who subscribed to that specific topic. This features ensures loose coupling and scalability of the pub-sub systems. Topics[4][5] are logical channels of related datasets, a subscriber receives all the data, which are published to the subscribed topic. The participants can be publishers and subscribers at the same time or only one of them. Messaging actions are not restricted to one topic, as well as publishing and subscribing can also be done on different topics.

The main advantage of this architecture, that the number of communicating system is highly scalable without the introduction of further point-to-point interfaces, thus the architecture remains transparent and manageable. **Fig. 4.** shows conventional interfacing (left) and an interfacing with pub-sub data distribution layer.

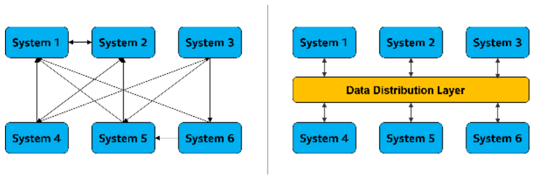

Figure 4*. Conventional interfacing (left) and interfacing with data distribution layer (right)*

III. Practical Implementation of the Framework

In this section we present a practical implementation of the data acquisition method described in the previous sections. In the experimental setup we collected the number of the working tool, the desired and remaining workpiece count of the tool, the z-axis position, the main spindle feed and current of an 3-axis turning machine.

The framework is also usable with state of the art and legacy IT systems. Some of the system are natively capable to communicate with message brokers, but there are cases when protocol translation and interfacing required, thus the usage of agents cannot be avoided.

There are other cases, when the source IT system cannot provide the source ID in accordance to the standardized naming convention, in this case the translation of the source ID requires the usage of agents too.

The following practical implementation presents the framework usage in case of legacy OT systems, but in case of legacy IT architectural setup of the framework is the same except from the source system. If the source IT system is capable to communicate with the message broker and can also provide the source ID in accordance to the standardized naming convention, the usage of the agents are avoidable.

1. Architecture of the Experimental Setup

The architecture of the experimental (**Fig. 5.**) setups contains the elements described in Section II.

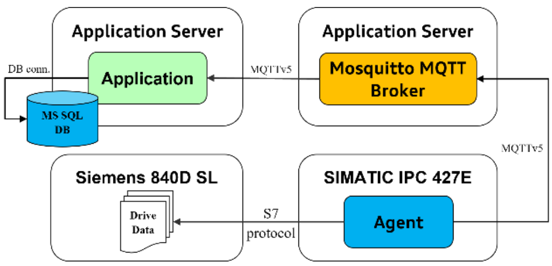

Figure 5*. Architecture of the practical implementation*

In the controller level we used a Siemens 840D SL [16] NCU with integrated S7-300 PLC. This device is capable to communicate through Profinet on Industrial Ethernet.

For the OT/IT Gateway we chose a SIMATIC IPC 427E [17] industrial PC with Ubuntu 20.04.5 LTS operating system, which besides of the hosting of the data acquisition agent, responsible for physical separation of OT and IT systems. The OT/IT Gateway can host multiple agents in different containers like Docker or LXC containers, and the gateway can be a remote server too. For the simplicity, in this work we used one physical hardware and one agent.

The data collection agent is a .NET [18] application written in C#, for the communication we used the Sharp7 [19] library, which implements the S7 Protocol [20].

For the data distribution layer we used an Eclipse Mosquitto MQTT broker [21] hosted on a Windows application server.

To store the data we created a simple .NET middleware, which subscribes to the specific topics and stores the data to a Microsoft SQL Server 2019 [22]. The middleware runs on a separate Windows server.

2. Data Collection

In the experimental setup we collected the tool number of actual working tool, the desired and remaining workpiece count of the actual tool, the main spindle feed and current in percentages, referring to the maximal current of the drive, and the position of the Z-Axis. The collected variables [23] shown in **Table 3**.

The sampling speed is based on the speed of the communication, which depends on the hardware type of the numerical control unit, and the user program, but cannot be faster than the smallest theoretical cycle time of the PLC. In this case, the sampling rate of the data acquisition agent is 500 milliseconds. The agent sends the collected data to the MQTT broker, the topic where the agent publishes the messages are the subtopics of "01/P/TestDomian/MG0001/MA001/…", namely "DesiredWorkpieceCount", "RemainingWorkpieceCount", "MainSpindleFeed", "MainSpindleCurrent" and "ZAxisPos".

3. Data Integration Layer

In the data integration layer we used an Eclipse Mosquitto MQTT Broker, hosted on an application server. For the simplicity of the setup, we only utilized the minimally necessary settings of the broker. We used the standard ports, 1883 for unsecure, 8883 for secure connection with Transport Layer Security. For the client to connect to the broker, we created an username and a password, and in the access control list (ACL) we defined which topics can the client access. The broker operates in retain mode, which means if a new client subscribes to a topic, the broker sends the last received message to the client in that topic. The quality of services (QoS) is set to QoS 0, which means "fire and forget", the broker sends the messages to the clients exactly once, without the need of confirmation if the message is arrived. This setting enables to communicate with the lowest latency. QoS 2 and QoS 3 are also available, with QoS 2 the message will be delivered at least once with the need of confirmation, with QoS 3 the broker send the message exactly once and requires a handshake mechanism with the clients. To ensure transparency and to help the debugging, logging is also enabled on the broker.

4. Middleware and Database

The middleware is a .NET application written in C#. For the MQTT connection we used the MQTTnet [23] library. The middleware subscribes to the corresponding topics and writes the data in an Microsoft SQL Database. The application uses the Entity Framework [25] and Data Transfer Objects (DTOs) to map the classes of the application to the database tables.

The database is "code first", which means the database tables are created based on the classes of the application, this feature and the Entity Framework also enables to the usage of the strongly-typed access to the data with LINQ [26]. With LINQ the data is easily accessible and manipulatable from the code. In this case the application stores the data without manipulation. The data from different topics are stored in different tables in the SQL Database. The database tables columns are ID (incremental ID as primary key), SourceID (Client ID based on standardized naming convention), TimeStamp (the timestamp of the data from the MQTT message) and the Value itself.

Table 3. *Collected NC Data*

Data	*Variable*	*Parameter*	*Machine Data*	*Format*
Actual tool number (ToolNo)	/Channel/State/actTNumber	-	$P_TOOLNO	UWord
Desired Workpiece Count	/Tool/Supervision/data[x,y]	ToolNo, 6	$TC_MOP13	Double
Remaining Workpiece Count	/Tool/Supervision/data[x,y]	ToolNo, 4	$TC_MOP4	Double
Main Spindle Feed	/DriveHsa/State/actualSpeed	-	$MD_1701	Float
Main Spindle Current	/DriveHsa/State/actualCurrent	-	$MD_1708	Float
Z-Axis Position	/Nck/MachineAxis/measPos1[axis]	3	-	Double

5. The Collected Data

As we previously stated in the beginning of section three, we collected the number of the working tool, the desired and remaining workpiece count of the tool, the z-axis position, the main spindle feed and current of an 3-axis turning machine. The following diagrams shows the above mentioned dataset of the tool T6013 during of four consecutive machining.

The main spindle feed is shown on **Fig. 6.** The X-Axis of the diagram represents the timestamps of the data in date and time format, the Y-Axis represents the feed of the main spindle in mm/s.

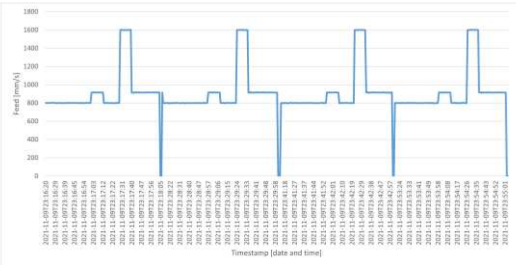

Figure 6. *Main spindle feed (X-Axis: date and time, Y-Axis: feed [mm/s]*

The absolute position of the Z-Axis is shown on **Fig. 7.** The X-Axis of the diagram represents the timestamps of the data in date and time format, the Y-Axis represents the absolute position in millimeters.

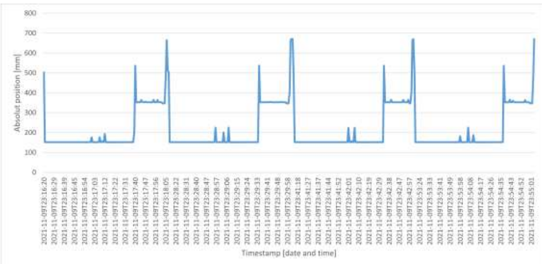

Figure 7. *Z-Axis position (X-Axis: date and time, Y-Axis: absolute position [mm])*

The main spindle current in percentage of the maximal drive current is shown on **Fig. 8.** The X-Axis of the diagram represents the timestamps of the data in date and time format, the Y-Axis represents the spindle current in percentages of the maximum current of the drive.

The count of the remaining workpiece count is shown on **Fig. 9.** The X-Axis of the diagram represents the timestamps of the data in date and time format, the Y-Axis represents the remaining number of machinable workpieces for the specific tool.

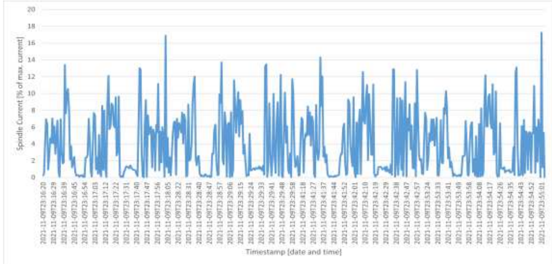

Figure 8. *Main spindle current in percentage of maximum current of the drive (X-Axis: date and time, Y-Axis: % of maximal current)*

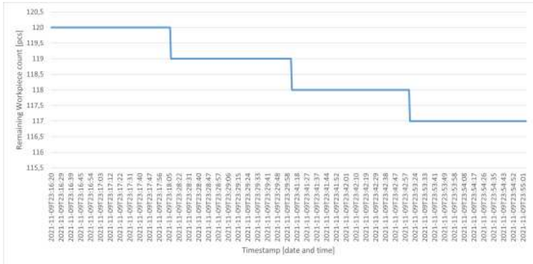

Figure 9. *Remaining workpiece count (X-Axis: date and time, Y-Axis: remaining workpiece count [pieces])*

The desired workpiece count is a specific, constant value for each tool, thus it is no depicted.

IV. RESULTS

Based on the results of the practical implementation of the data integration framework, we rolled out the solution to an entire production line of the AUDI HUNGARIA Zrt. The pilot production line includes 36 machines, each are connected to the data distribution layer through agents as in the previous section presented.

We collected the data of the machine states, machine information like part counters and cycle time measurements, workpiece movements, operator identification information, error messages, the energy consumption, feed override of the machines and the MQTT State of the agent. The topics, where the agents are publishing the data, are based on the standardized naming convention. The base of the topics is the machine ID within the hierarchical structure of the factory, business unit, production domain and the production line, which follows the pattern: “Factory ID/Business Unit /Domain/Production line/Machine ID/Topic”. The average daily number of messages for each topic and the size of each message are shown in **Table 4**.

Table 4. *Collected NC Data*

Topic	*Message Count*	*Avg. size (Byte)*
MqttState	2	128
PartMovement	10010	234
Energy	42657	147
MachineState	15504	131
MachineInfo	10010	240
Messages	37053	93
Operator	2	188
Override	251	130

The average daily message count of the 36 machines is 115000 messages. The messages are stored in an SQL Database for further analysis and visualization tasks.

V. Summary and Future Work

In the previous sections we presented a data collecting framework to collect data from OT/IT systems and prevent interface jungle, thus simplify the architecture of a corporate network and enable new data processing use-cases. The framework enables to collect data from legacy OT and IT system, that are unable to use state-of-the-art communication protocols or meet data governance requirements.

With the proposed elements, like the standardized naming convention and the usage of data collection agent and the data distribution layer, the connection of related data can be simplified and the difficulties caused by the poorly managed system and the lack of change management can be eliminated. The standardized naming convention can also be used as a part of asset management.

With the introduction of the data distribution layer, the point-to-point interfaces can be avoided, thus the network management and operations becomes simpler. The data distribution layer also provide transparency and traceability trough data access policies, user management and logging. Specific users or clients can only access to topics, which are enabled in the access control list of the broker, read and write privileges can be set up also, and the connection attempts of client are also logged. These functionalities also enable the conformity to IT security rules.

The framework enables the data collection from legacy systems, thus the operational and process data can be collected from heterogenous systems in a standardized way. The standardized message structure makes the data handling and storage easier, the newly connected clients only have to meet the requirements of the standardized naming convention and message structure to send data to the broker. This feature enables data storage without any further customization of the data sources. The standardized message structure also specifies the topic for the data. This property enables the clients to subscribe only to that topics, what it really needs. This function also eliminates the need for data lakes, each use-case only have to collect the data, what they really need.

In case of a new use-case needs access to the data which available on the message broker, a new user must be created on the broker and after the access right granted on the topic which the new client needs, it can subscribe to the topic and can start the data collection from the broker. This feature enables fast on-boarding of new data processing use-cases, such as machine learning models, artificial intelligence (AI) based data processors and predictive systems.

The data integration framework provides a good starting point for industrial artificial intelligent applications through simplifying the data collection, management and distribution of process and machine data, and new data collections can be easily introduced to the data distribution layer.

Further research in the processing of the collected data, for example predictive maintenance systems and AI backed quality assurance systems strongly advised.

Author Contributions

B. Szűcs: conceptualization, proof of concept setup, programming, writing and editing.

Disclosure Statement

The author declare that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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A survey on efforts to apply IPv6 in V2X communication networks

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Abstract: This survey focuses on the application possibilities of using Internet Protocol (version 6) in Vehicle-to-Everything (V2X) networking architectures by analyzing existing standards and related papers in this field. The article explains the terminology used in IP-based V2X networks, introduces the considered use cases, and gives an overview of the three standardized options applying IPv6 in vehicular environments: IEEE WAVE provides networking services to applications in vehicular networks through IPv6, IPv6 over 802.11-OCB can be implemented in Wi-Fi-based ad hoc vehicular networks for both V2V and V2I, and the Geo Networking IPv6 adaption sub-layer (GN6ASL) for IPv6 support in the ETSI ITS protocol family. The paper also highlights non-standardized solutions and available techniques designed for IPv6-based V2X infrastructures, summarizes wireless connection requirements, and mobility management needs, together with the newest research efforts aiming at the applications of IPv6 in V2X communications.

Keywords: Vehicle-to-Everything (V2X); Internet Protocol version 6 (IPv6); vehicular ad-hoc networks (VANETs); IEEE 802.11-OCB; WAVE; GN6ASL

I. INTRODUCTION

V2X is a networking concept for exchanging messages that contain status data and vehicle attribute information in the cooperative and legacy Intelligent Transport Systems (ITS/C-ITS) domain. It allows a vehicle to connect with every transportation participant, such as in the context of Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle to Network (V2N), and even introducing pedestrians (V2P) or smart power grids (V2G) [1] into this system. V2X networks have two primary, currently available communication techniques. The first and initial one is the Dedicated Short Range Communications (DSRC) standard (known as ITS-G5 in Europe) which is based on the Institute of Electrical and Electronics Engineers (IEEE) 802.11 Wireless-LAN-based (WLAN) standard family. The second is the mobile cellular communications-based solution (Cellular V2X) which relies on the standardization results of the 3rd Generation Partnership Project (3GPP) [2].

DSRC is classified as the Wi-Fi-based V2X technique, using the IEEE 802.11p specifications under IEEE 802.11-2016 (the standard specifying physical (PHY) and MAC layers for wireless communication between moved or fixed stations (STAs) within a local region). IEEE 802.11p or IEEE 802.11-OCB (Outside the Context of Basic Service Set) was designed for ad hoc Wi-Fi networking and to assist in the various vehicular scenarios needed for V2X system operations [3].

However, IEEE 802.11p is an officially accepted amendment to the well-known IEEE 802.11 standard, which is widely recognized as Wi-Fi. Its primary focus is on fulfilling the requirements of vehicular communication systems by introducing protocol improvements that ensure swift and dependable communication in situations involving high-speed mobility. Through modifications to the existing 802.11 standards, 802.11p enables efficient communication among vehicles in V2X scenarios, encompassing both V2V and V2I interactions [4]. Furthermore, IEEE 802.11p is the cornerstone of the IEEE 1609 family of standards [5] created for road safety systems unified by Wireless Access in Vehicular Environments (WAVE) specifications. On the one hand, IEEE 1609 specifies a vehicular communications protocol stack for both safety and non-safety purposes. On the other hand, WAVE standards describe an architecture as well as a complementary, consistent range of services that allow stable V2V and V2I wireless communications. These standards, when combined, pave the way for a wide variety of transportation technologies, including driver safety, electronic tolling, improved navigation, and traffic control [6]. A package of IEEE 1609 standards was adopted for trial use in 2006 and 2007 [3]. IEEE 1609.0 standard defines the WAVE architecture and the facilities required for multi-channel DSRC/WAVE systems, while IEEE 1609.1 describes resource manager specifications. IEEE 1609.2 is the standard for vehicular security, IEEE 1609.3 specifies network layer services and transport layer services, and IEEE 1609.4 defines multi-channel extensions to the IEEE 802.11-2012 Medium Access Control (MAC) layer [7].

In current 802.11p-based systems, Internet Protocol (IP) is not applied: although standards support the application of IP in the networking layer, non-IP solutions have become widespread in practice. The issue with IP is that it requires more bandwidth which is why they are not utilizing it right now. IP, with its transport layer (TCP and UDP), is not a lightweight protocol; the stack implements extensive headers because it is a more general purpose, not concentrating on the issue that we want to address in the ITS domain. Besides the overhead of sub-optimized header structures, tackling latency requirements could also be a problem for IP in the case of real-time safety V2X applications and services.

Cellular V2X (C-V2X) transmits and receives signals via 3GPP fourth-generation (4G) or fifth-generation (5G) and beyond communication. It employs two distinct transmission modes. The first is direct contact between cars, utilities, and pedestrians on the road. Cellular V2X can operate independently of a cellular network in this mode. For correspondence, it employs a PC5 interface. In contrast, the second mode is cellular network communications. C-V2X uses a traditional mobile network to provide information about road and traffic conditions in the field to cars. For correspondence, it employs the Uu interface, the Uu interface utilizes LTE's and 5G NR's uplink and downlink capabilities to establish vehicle-to-vehicle communication. On the other hand, the PC5 interface, also known as sidelink communication in cellular terminology, employs a similar method to DSRC to enable direct connections between vehicles [8]. IP is applied in the Uu interface, but in PC5, it is only an option currently that is rarely considered in actual implementations. Figure 1 summarizes where IP is used in V2X infrastructures nowadays.

The role of vehicular networks within the ITS/C-ITS research area considers new and existing vehicular services, such as fleet management and road pricing. These intelligent environments include services related to transportation and traffic management modes, allowing people to be more aware and use transportation infrastructure. These provide sophisticated telematics using hybrid networks, such as (IP-based) communications and non-IP ad-hoc direct contact between vehicles and infrastructures employed at the same time [9]. Although IP has numerous promising features for V2X applications (e.g., works as a unification layer, provides interoperability, ensures portability and wider deployment) and several efforts are calling for IP to be used in PC5 and DSRC, until these days, those efforts remained sporadic. This article aims to raise awareness of the potential benefits of IP-based V2X solutions.

The current version of the Internet Protocol IPv4 is becoming outdated due to its small address space, lack of required functionality, and insufficient built-in security features. The Internet Protocol version 6 (IPv6) [10] was standardized and intended to replace IPv4 because it suffers from a depleting 32 bits-long address space, affecting Internet continuity's growth, and is no longer scalable for future use. IPv6 offers many benefits that meet the critical needs of cooperative vehicular connectivity, such as the enormously broad address space provided by the enhanced 128 bits long addressing and the built-in and secure Mobile IPv6 protocol family for efficient IP-level mobility management [11].

However, in novel Internet use cases and networking environments, such as V2X, it is intended to rely solely on IPv6-based technologies. Of course, it is a tremendous benefit of IPv6 that it has an enormous address space which is useful when designing ever-growing V2X networks, their technologies, and services. The IPv6 protocol is generally regarded as a widely accepted, standardized protocol that will be predominant for future communication [12].

Currently, there are three major standardized options to apply IPv6 in vehicular networks. IEEE WAVE provides networking services to applications in vehicular networks through IPv6 as an optional networking layer, IPv6 over 802.11-OCB, which can be implemented in IP-based vehicular networks for V2V and V2I for 802.11p-based infrastructures, and the GeoNetworking IPv6 adaption sub-layer (GN6ASL) that provides IPv6 communication capabilities over non-IP Geonetworking mechanisms.

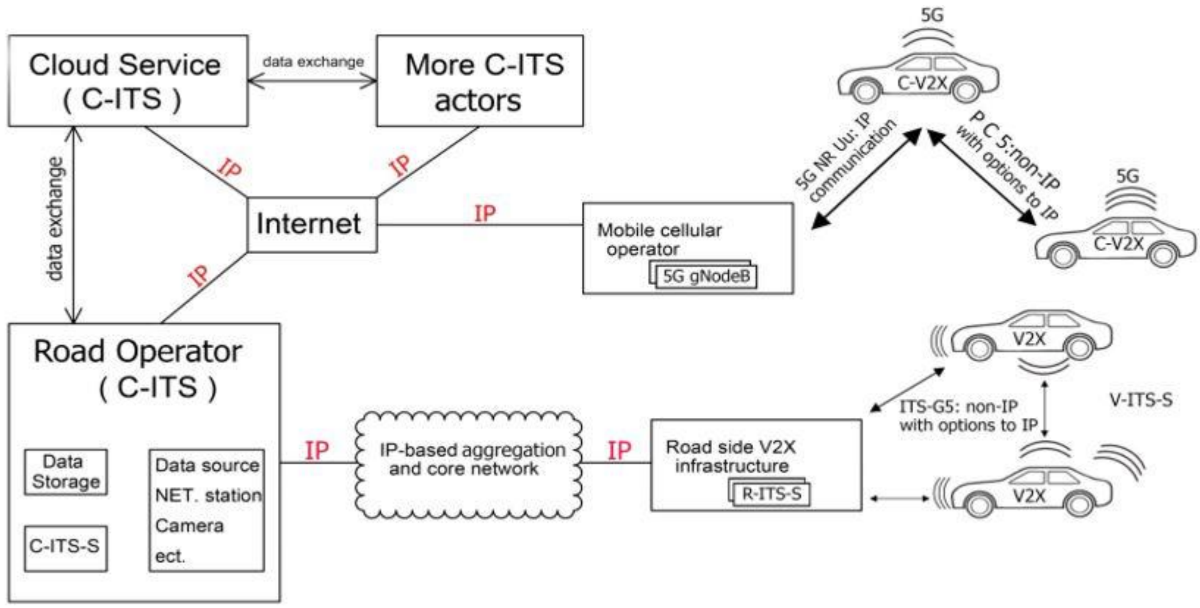

Figure 1. *IP in current V2X infrastructure*

This paper is divided as follows. Section 2 summarizes the motivations and use cases of IP in V2X. Section 3 briefly describes the currently available, most significant standards. Section 4 introduces existing surveys from the domain and presents recent IPv6-based V2X solutions or IPv6 extensions designed for V2X support from the literature. Finally, Section 5 contains our final remarks and conclusion of the paper.

II. Motivations and use cases of IP in V2X

As we all realize, today's communications environment is exceptionally intricate, but it will be kept together and given coherence by the IP, which serves as the global language that underpins and connects all the elements of this ecosystem. Even though IP does not play an essential role nowadays in V2X deployments, the technological advancements of IP communications have substantially enhanced available solutions and allowed the V2X networks to move toward integrating systems. The main reason is that IP provides a unified layer for underlying technologies and higher-layer applications.

The IP-based communication APIs and the widespread infrastructure support ensure interoperability, such as a vehicle or a router when linked to the Internet; they enable any other local area network or radio network to attain a certain level of smooth cooperation. The utilization of IP is not confined to a specific domain. Instead, it can be applied across a wide range of industries, including but not limited to the World Wide Web, healthcare, government, education, and even V2X communication.

Most new vehicles have embedded built-in or connected brought-in Internet access, or a combination of the two. Vehicles with embedded connections have a built-in radiosystem that receives mobile cellular data directly using the 4G and 5G Uu interface. At the same time, some with connected connectivity use the driver's smartphone data to access the Internet for many reasons (e.g., video streaming, web browsing, and peer-to-peer). Moreover, interoperability is the capacity of systems, applications, or networks from various gateway to work together in a coordinated manner without the intervention of an end user. Interoperability enables unlimited data and resource sharing between systems through local and wide area networks, and this strategy allows the IP to ensure portability.

IP technology allows for the wider implementations and use of OTS (off-the-shelf) applications and services. On the one hand, IP networking is more affordable and accessible, allowing for rapid and cost-effective expansion of network endpoints. On the other hand, IP-based products can be easily updated to fix security issues or add new features.

Although non-IP became essential for early adopters due to its latency power, focused functionality, and well-scoped, safety-centric application areas, IP-based vehicle data transmission via wireless networks as a critical vehicle data application domain has also become significant in the scientific community. Due to IP's flexibility, multiple application areas have been broadly described in automotive research and department activities in recent years. Vehicles lacked suitable, cost-effective wiring technology, so IP introduced a new approach. According to an integration required to maintain an ever-increasing level of security, IP provides performance and maximum security to V2X [18]. There will be a significant benefit to connecting the IP and the vehicles and a large number of function applications based on this linking basis. Through the unique IP address, we can conduct remote access to specific automotive data, perform online operations, and perform remote defect diagnostics [13].

However, the IP's general portability and well-defined APIs are the primary motivation for its use in V2X. IP is a standardized communication protocol that enables long-term and sustainable use because of its widespread deployment in many industrial fields [14]. Moreover, the standardized network technology would simplify communication that would alleviate the usage of IP in the vehicle while also simplifying the vehicle's design. In addition, IP-based technologies entail a large body of knowledge already available, allowing for improved development, maintenance, and testing. Widespread use of IP, standardization, and openness, as well as an ample supply of high-quality chips on the market, leads to low product development and manufacturing costs. Also, IP could potentially pave the way in V2X for improved navigation, location-based services, and remote diagnostics [15].

In the automotive use cases of the 5G and beyond mobile cellular ecosystem, edge computing technology will provide an end-to-end architecture for distributing computing operations over localized networks. Using edge computing and improved network architecture increases the capacity to accommodate extensive automotive data exchange between vehicles and the cloud in a sensible manner [16]. Edge computing technology implementations nowadays mainly focus on IP since the access relies on the Uu interface, where IP is initially implemented, to support a generic platform where IP-based communication enables easy application development and deployment. Of course, PC5-based ad hoc V2X communication could benefit from IP compatibility similarly.

V2X Public-key Infrastructure (PKI) is a system that uses digital certificates to secure communication in vehicular networks. These digital certificates are used to verify the identity of the communicating devices, such as vehicles and roadside units, ensuring that only authorized devices can communicate with each other. The digital certificates used in V2X PKI contain information such as the device's identity, its public key, and the certificate authority's digital signature, which is used to verify the authenticity of the certificate. These certificates establish trust between the communicating devices and ensure that only authorized devices can participate in the communication.

Even non-IP V2X (current DSRC or PC5 implementations) cannot work without having a mobile cellular IP data connection because PKI mechanisms require Internet access. Since the security mechanisms rely on the IP link for the certificate communication, PKI needs to communicate with the infrastructure on the IP part of the architecture, which requires IP data exchange [17].

IP is a critical technology for 5G and beyond V2X/C-ITS deployments that support Uu communication and the Internet of Things (IoT) paradigm evolving towards the vehicular Internet. It also makes it easier to apply and use IP-enabled applications in vehicular communications [18]. For that, there are many benefits of IP in V2X; we can state some of them, such as large address space, which impacts the expansion of Internet continuity. Improved end-to-end connectivity, security service, and mobility. Furthermore, the inclusion of node auto-configuration mechanisms to aid in configuring connected vehicles, among other things. Also, it has a standard communication API and common addressing design. In addition, it is inter-domain communication without gateways, and finally, the transmission is independent of the physical network technology [14].

Pedestrians, and other Vulnerable Road Users (VRUs), such as bicyclists, may utilize their smartphones in various ways; For example, a pedestrian can acquire unique information that will be valuable for attracting attention throughout the activity. Aiming that, VRU protection through Vehicle-to-Infrastructure-to-Pedestrian (V2I2P) networking, such as safety aware navigation services, form another primary motivation and application area for IP in V2X; a vehicle and pedestrian using a smartphone connected with a network device for wireless communication with an RSU can avoid collisions. Moreover, vehicles and pedestrians can connect through an RSU, which provides wireless communication scheduling information [19].

In addition, a Tele-operated Driving (ToD) service can also become a significant advanced V2X use case driving V2N spectrum demand, and spectrum regulators must consider this to facilitate connection and automated mobility applications [20]. Furthermore, a remote driver runs a host vehicle in this use scenario. The host vehicle can accomplish this by providing video and sensor data to the remote driving through the uplink and receiving driving directions via the downlink [21], presumably over IP-based communication.

Internet Protocol appeared in practical V2X deployments to provide efficient, secure, and scalable communication between vehicles and other road users. A good example is Tiempo Secure, a company that is taking a leading role in promoting the use of IP in V2X communications [22]. They have invested over 13 years in developing unparalleled security IP, expertise, and secure software libraries allowing their clients to achieve the highest levels of security for their semiconductor products. Tiempo Secure has stated that IP integration is crucial for V2X communication, and their extensive experience and resources in IP-based security make them a valuable partner for organizations looking to implement V2X solutions. Another example is YOGOKO, a company that is taking the lead in end-to-end connectivity between vehicles and other road users, also advanced internet connectivity such as IPv6, which are utilized to provide expanded connectivity independent of existing access methods and accessible to users, services and applications [23].

III. Current major standards for IPv6-based V2X networking

3.1 The IEEE WAVE networking service

IEEE WAVE is divided into architecture, security services for application and management messages, and networking services (see Figure 2 for details). In this portion, we will discuss the networking service component of IEEE WAVE. Network services are a list of management plane and data plane functions defined in the specification at the network and transport layers that support WAVE communications. Furthermore, it specifies Wave Short Messages (WSM), which provide a WAVE-specific counterpart to IPv6 that applications can explicitly support. This standard also includes a Management Information Base (MIB) for the WAVE networking protocol stack [24].

WAVE networking services are part of the open system interconnect (ISO) communication stack's layers three (networking) and four (transport). [25]. WAVE Short Messages Protocol (WSMP) is a protocol used by DSRC networks to communicate safety information between vehicles and the roadside or just between cars [26].

The IEEE 1609.3 standard, by its practical feature, facilitates IPv6 address autoconfiguration without using the IPv6 Network Discovery (ND). The WAVE service advertising (WSA) for accessible service information transmitted by a WSMP message provides this functionality [7].

This specification aims to include addressing and routing facilities within a WAVE structure, allowing multiple stacks of upper layers above WAVE Networking Service and several lower layers below WAVE communication networks [25]. The Networking Services management functions monitor the transmit parameters (such as data rate and power levels for sending management frames defined in IEEE 1609.4) of data plane traffic [25].

On one hand, the IEEE 1609.3 Management plane facilities are referred to as the WAVE Management Entity (WME), and they provide Registration of an Application as one of the six practical tasks which are [24]:

- Registration of an Application
- Administration of WAVE Basic Service Sets (WBSS)
- Monitoring of channel use
- Configuration of IPv6
- Control of the received channel power indicator (RCPI)
- MIB maintenance

On the other hand, the IEEE 1609.3 Data plane facilities, which are designed for air interface performance and low latency in favor of vehicular applications, consist of the following [25]:

- Logical Link Control (LLC)
- WSMP
- IPv6
- Transmission Control Protocol (TCP) and other transport layer protocols User Datagram Protocol (UDP)

The TCP/IP stack in the network protocol stack follows IPv6 rather than IPv4 to take advantage of IPv6's immense address space and multiple mechanisms for auto-configuration. This IP stack accepts TCP and UDP as transport layer protocols and routes payloads for IP based on the transport layer protocol's port numbers [7].

3.1.1 Wave Short Message Protocol (WSMP)

WSMP protocol for the WAVE network layer allows for high-priority and time-critical connectivity [27]. The propagation of WSMP packets is a significant addition to WAVE networks. However, the WAVE standards require transmitting each WSMP packet using: a specified in-packet data rate, a defined in-packet channel number, and a defined in-packet transmission capacity [26].

3.1.2 Internet Protocol version 6 (IPv6) support

The WAVE standards workgroup adopted Internet Protocol version 6 (IPv6) as the network layer protocol. This decision reflects the WG's commitment to embracing modern and future-proof technologies within the WAVE standard framework. By selecting IPv6, the workgroup acknowledges the need for an advanced, scalable, and robust network layer protocol to support the diverse requirements of vehicular communication systems [26].

In addition to IPv6, the WAVE standard also supports the UDP (User Datagram Protocol), and

TCP (Transmission Control Protocol), protocol suites. This protocols are crucial in facilitating reliable and efficient data transmission within WAVE networks. The LLC sublayer is where IP traffic is sent and received [27].

3.1.3 Logical Link Control (LLC)

The LLC sublayer is used in Networking Services for both IPv6 and WSMP traffic. Moreover, the header of the LLC sublayer is just 2-octet long and includes an Ethertype that defines the higher layer protocol [25]. With a MAC frame field called Ethertype in the LLC header, the LLC sublayer identifies whether a WAVE MAC frame is meant for the safety application protocol stack or the non-safety application protocol stack [7].

3.1.4 Registration of an Application

To use WAVE networking facilities, all programs must first enroll with the WME. Each program is assigned a distinct provider service identifier (PSID). The registration data is stored in three tables, which are as follows: table of Provider Service Info, User Services Information Table, and Status of Applications Table [24].

3.1.5 WAVE Management Entity (WME)

It is a set of managerial functions that are needed to provide WAVE Networking Services [25]. Moreover, it performs WAVE Networking Management Services tasks such as handling services requests for higher layers, assigning channels, tracking WAVE Service Announcements, configuring IPv6 using data obtained from other WAVE devices, and maintaining MIB [27].

3.1.6 Maintenance of the Management Information Base (MIB)

The WME in a controlled WAVE system must keep a MIB containing configuration and status information. Higher Layers can navigate the MIB using WME-Get and WME-Set. Furthermore, the system can support additional MIBs linked to Networking Service (such as MIBs relevant to IPv6) [25].

3.1.7 WAVE Basic Service State (WBSS)

A BSS category includes a group of stations collaborating by operating in WAVE mode and communicating through a common Basic Service Set Identifier (BSSID). Moreover, WBSS is initiated when the radio in WAVE mode transmits a WAVE beacon containing all the data required for a receiver to enter [4].

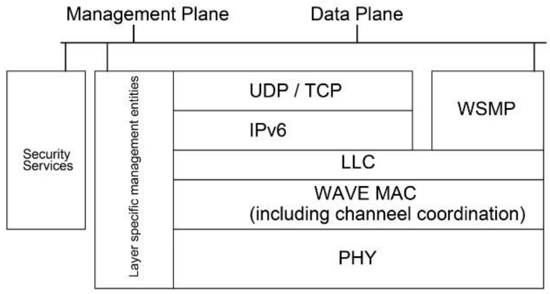

Figure 2. *The standardized protocol layer structure of WAVE*

3.2 IPv6 support in 802.11-OCB based ad hoc networks

The term OCB refers to a mode of service in 802.11-2016 networks, where a station (STA) is not part of the Basic Service Set (BSS) and does not use IEEE 802.11 authentication, affiliation, or data protection [28]. The IEEE 802.11-OCB mode is the ground base of the DSRC system (also known as ITS-G5 in Europe), making it simple for vehicles to connect [29]. The following are the significant characteristics of OCB mode: no IEEE 802.11 Beacon frames sent, no authentication is needed, and no affiliation is required [30].

Furthermore, WAVE also uses IEEE 802.11-OCB networks for vehicular communications.

Two stations (STAs) are connected through IEEE 802.11-OCB following in the considered link model. STAs in vehicular networks may be IP Road Side Units (RSUs) or IP On-Board Units (OBUs). Both connections are peer-to-peer, and several links may exist on the same radio interface. Although the IEEE 802.11-OCB standard is well-defined, and a legacy IPv6 stack will run on those connections, vehicular communications use opens up new possibilities [31].

The IPv6 protocol enables connectivity between nodes in close proximity through a single IEEE 802.11-OCB connection with minor modifications to the current protocol stack and just a few restrictions [28]. Moreover, allowing vehicles to link to the Internet through IEEE 802.11-OCB has received little attention, especially in the sense of IPv6 [29]. The IPv6 network layer works precisely the same way on 802.11-OCB as it does on Ethernet with the following variations: 1) Expectations owing to the difference in the process of the IPv6 network layer on IEEE 802.11 versus Ethernet; 2) Expectations attributable to the OCB existence of 802.11-OCB versus IEEE 802.11 [31]. In addition, Figure 3 depicts a more theoretical and extensive perspective of connections between IPv6 and 802.11-OCB layers [31]. In contrast, EPD is an Ethertype Protocol Discrimination that is runs on the top of the IP layer, and Link Layer Control Service Access Point (LLC_SAP) is the connection between IPv6 and EDP.

We introduce the essential characteristics of using the IPv6 protocol in IEEE 802.11-OCB-based V2X networks in the following sub-sections.

3.2.1 Maximum transmission unit (MTU)

On 802.11-OCB, the default MTU for IP packets is 1500 octets; however, any Internet connection must have a minimum MTU of 1280 and comply with all the other guidelines, including those concerning fragmentation [31]. In today's networks, a value of 1500 octets is considered the de facto standard [28].

3.2.2 Frame structure

IP packets must be sent as Quality of Services (QoS) data frames over 802.11-OCB. An 802.11-OCB packet is directly followed by an LLC header and an 802.11 header. In compliance with Ethertype Protocol Discrimination (EPD), 0x86DD must be set for the Type field in the LLC header. To give priority to traffic that is safety-critical and time-sensitive, it is advised to designate a priority value of 1 for the 802.11 data service mapping. By assigning a higher priority value, the system guarantees that this particular type of traffic is prioritized above other forms of data, enabling the prompt and dependable transmission of vital information [31].

3.2.3 Link-Local Address

If an Extended Unique Identifier (EUI-64) is used to form IPv6 link-local address, the procedure for doing so is the same as creating an IPv6 link-local address on Ethernet connections [31]. EUI-64 is an IPv6 link-local address created by mixing 16-bit 0xFFFE with a 48-bit MAC address. A collection of vehicles can construct a network structure out of 802.11-OCB interfaces, and the network must utilize an IPv6 link local prefix. The interfaces must also be allocated link-local IPv6 addresses [7].

3.2.4 Interface ID generation

According to the IPv6 Link-Local address development principles, the Interface ID (IID) is obtained from a physical (MAC) address in the standard way, using the EUI-64 protocol, and it has a length of 64 bits [28]. A predetermined prefix and the Interface ID are used to generate a link-local address. Furthermore, as a part of IPv6 Neighbor Discovery (ND), IPv6 employs Duplicate Address Detection (DAD) to ensure the distinction of an autoconfigured IPv6 address [7].

3.2.5 Address mapping

The guidelines for creating and mapping unicast and multicast addresses are the same as for IPv6 protocol service over IEEE 802.3 (Ethernet) and IEEE 802.11 (Wi-Fi) networks [28]. For unicast address it is a single interface's identification; when a packet is transmitted to a unicast address, it is sent to the interface specified by the address. While for multicast addresses, it is an identification for a collection of interfaces when multicast packets are transmitted to all interfaces designated by that address [32].

3.2.6 Subnet structures

When V2X network nodes are in close proximity, a subnet structure can be created [28]. IPv6 Neighbor Discovery (ND) is an essential component of the IPv6 suit. It is intended for transit and point-to-point connections (e.g., Ethernet). Moreover, IPv6 ND is assumed that the link layer can have adequate and secure multicast support for a variety of network operations, such as MAC Address Resolution (AR) and Duplicate Address Detection (DAD) [33].

IPv6 ND protocol necessitates reflexive properties (bidirectional connectivity), usually in P2P OCB connections. As a result, mapping an IPv6 subnet on an OCB network is only possible if all network nodes share a common physical broadcast domain. Furthermore, IPv6 ND necessitates nodes' continuous connectivity in the subnet to protect their addresses [31].

Finally, in P2P connections over IEEE 802.11-OCB, the baseline ND protocol must be supported since the IPv6 ND protocol for Ethernet was developed [28]. The general assumption of a stable multicast is not guaranteed, nor is the function of ND, DAD, and AR. Multicast communications over wireless networks are inefficient and disruptive to unicast traffic [12].

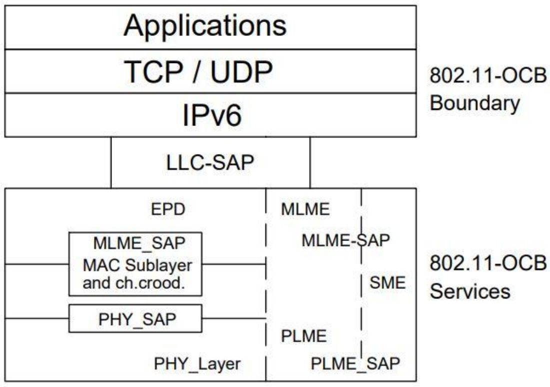

Figure 3. *The paradigm of IPv6 protocol utilization on an IEEE 802.11-OCB link*

3.3 GN6ASL: an adaption layer for IPv6 in V2X networks

3.3.1 ETSI ITS Architecture

The ETSI TC ITS has standardized the GeoNetworking (GN) protocol for routing packets via VANET (Vehicular Ad-Hoc Network) in its system architecture. The GN protocol employs the spatial routing theory, which routes packets depending on the geographical position of network nodes and the packet's destination [34].

The ETSI EN 302 636-6-1 standard [35], defines IPv6 packet transfer over the GeoNetworking (GN) Protocol. The GN protocol is a geographical addressing and routing scheme. With the prevalence of GPS systems, it is known that all nodes are aware of their own geographical location. Furthermore, they discover the location of their immediate neighbors [34]. An adaption sub-layer is specified for IPv6 transmission and is known as the GeoNetworking IPv6 adaption Sub-Layer (GN6ASL), which avoids changes to the standard IPv6 protocol [34]. The GN6ASL is responsible for connecting the IPv6 layer to the GN layer, allowing the GN layer acts as a sub-IP layer in IPv6. IPv6 datagrams are received by the GN layer, which encapsulates them into GN packets, adds a GN header, and sends them [34]. However, the GN protocol supports both point-to-point and point-to-multipoint communications and geographically scoped addressing techniques such as Geo-Anycast and Geo-Broadcast [35].

GN6ASL is a Geo-Networking adaption sub-layer that allows IPv6 packets to be transmitted over the network. The IPv6 layer is introduced to GN6ASL as a link-layer protocol that is based on Geo-Networking [35]. The GN6ASL standard distinguishes three types of virtual connections. The first virtual connection is reachable through symmetric links, using IPv6 ND with Stateless Address Autoconfiguration (SLAAC). In contrast, the other two are in a domain that can be transmitted, which are IPv6 link-local multicast packet distribution and IPv6 packet transmission across geographic boundaries [7]. SLAAC can be used in multi-hope vehicular ad hoc networks by leveraging the vehicle's geographical position recognition capability. The definition of IPv6 connection is applied in SLAAC to a well-defined geographical region connected with a connection point to an infrastructure-based network that serves as the IPv6 Access Router (AR) [36]. Furthermore, AR connects an ad hoc network to the Internet. The Geo ad-hoc router implements both the Geo Networking protocol and the GN6ASL. The Geo Ad-hoc and access router are logical network components that operate independently [35].

In addition, the Geo-Networking protocol offers a sub-IP multi-hop delivery service to upper layers. The services provided by GN6ASL to IPv6 are distributed by GN6 Service Access Point (SAP), which is built on the service user/provider model. GN SAP refers to a subset of the data SAP supported by Ethernet IEEE 802.3 to ensure backward compatibility with legacy IPv6 protocol implementations [35]. The architecture of GN6ASL in an ITS station is depicted in Figure 4.

The GN6ASL uses the GN geo-broadcasting capabilities to form link-local multicast messages to geographical regions [36].

3.3.2 GeoNetworking Protocol-provided services

GeoNetworking is a geographical routing protocol that distributes packets across the vehicle depending on node location. Nodes are expected to get their own geographical position through a location system. Upper protocol entities are serviced by the GeoNetworking protocol. In addition, the services are delivered through the GN SAP utilizing service primitives of various sorts that hold parameters and the top protocol entity's Protocol Data Unit (PDU). In GeoNetworking, a PDU of transport is designated a Service Data Unit (SDU). The SDU is supplemented with Protocol Control Information (PCI) and sent as a GN PDU to the peer entity. The GeoNetworking protocol uses the ITS Access Layer to deliver packet transport services. The GeoNetworking protocol defines several types of packet delivery services, including single-hop broadcast, Geo-unicast, Geo-broadcast, TSB (Topologically-Scoped Broadcast), and geo-anycast [37]. In Geo-unicast, the packet is sent hop by hop toward the endpoint and transmitted to the particular node. Furthermore, in Geo broadcast, the packet is geo-routed to a particular geographic zone and transmitted to all nodes inside the endpoint area [34].

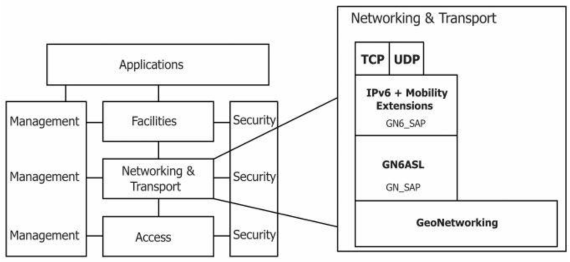

Figure 3. *The architecture of GN6ASL in an ITS station*

IV. IPv6-RELATED PROPOSALS FOR V2X SYSTEMS

As V2X systems progress, there is an increasing demand for reliable and future-proof connectivity solutions. The rise of IoT and the growing presence of connected vehicles and intelligent infrastructures necessitate addressing the limitations of current communication protocols in V2X systems. This advocates for adoption IPv6 as the standard communication protocol for V2X systems.

IPv6 offers numerous advantages compared to its predecessor, IPv4, which currently still even the IP-based V2X deployments. The primary advantage lies in the significantly expanded address space of IPv6, allowing for an almost limitless number of unique IP addresses. Given the expanding number of connected vehicles, infrastructure, and IoT devices, this scalability is crucial to accommodate the expected exponential growth of V2X networks.

4.1 Existing surveys

Available survey papers in the literature already cover some aspects of IP-based vehicular networking. Before highlighting recent research efforts on IPv6-equipped V2X, we introduce these surveys and highlight their main results.

In the article [38], the authors investigate the ITS discussions at the IETF and offer hope for TCP/IP protocols in vehicular communications, as TCP/IP protocol stacks are already present in many vehicles that are linked to the Internet. Furthermore, the authors analyzed the issue statement regarding the usage of IP in vehicle networks, highlighting the benefits of a narrow waist networking layer, including the support for link layers such as 802.11-OCB with a range of modulation methods. In addition, a proposal for an ITS WG was presented to standardize and profile IP protocols for establishing direct and secure communication between moving networks.

In the paper [7], the authors examine IP-based vehicular networking, which is characterized as vehicular networking that is purely based on the IP, and investigate the upcoming smart road vertical Internet of things (IoT) and Multi-access Edge Computing (MEC) applications. This paper focuses mainly on combining intra- and inter-vehicular networks and mobility management within the broader sense of globally protected IP vehicular networking. Furthermore, the authors address the core aspects of IP-based vehicular networking, emphasizing network architecture, IP address autoconfiguration, and accessibility control. In conclusion, this paper discusses the present and future paths of IP-based vehicular networking and solutions for self-driving cars, partly autonomous vehicles, and autonomous vehicles on smart roads.

The article [39], provides an overview of the contemporary internetworking architecture and engineering aspects. The author's objective in writing this survey is to show the deterioration of initial design goals and motives. They intend to develop a new set of rules that might be used to hypothesize architectural concepts for future network architecture. Furthermore, the authors demonstrate that the roots of Internet architecture are solid and well-engineered. Also, the authors of this paper discussed two topics: the design decision that led to the present network architecture and the impacts of this network architecture in terms of inertial effect, which make it hard for the Internet to advance from its current condition. In addition, regarding the V2X scenarios, the platform must be able to collect real-time data from various sources (e.g., road conditions, approaching signals, etc.) in order to make the right decisions about traffic stream and public safety while guaranteeing that the decision is served to an autonomous vehicle instantly, any delay causes knowledge to become outdated and useless. As a conclusion, looking ahead at new applications, the Internet as a single system will be hard to scale; it is easier to grow and embrace in multi-instance contexts.

The study [40], intends to provide both an introduction to vehicular networking for readers with a wide range of technical backgrounds and a comprehensive analysis and categorization of state of the art. The article is organized to guide the reader through the growth of the vehicular networking sector, moving from high-level aims to more granular solutions. In addition, the authors of this study describe the fundamental properties of vehicular networks, as well as an overview of applications and associated needs, obstacles, and possible solutions. Moreover, they have presented an overview of significant ITS initiatives and projects in the US, EU, and Japan, both present and past. Subsequently, the authors of this survey describe mainly concerted initiatives, which include standardization attempts and large projects.

Motivated by the potential of IPv6, ETSI also released a group report focusing on the general questions of IPv6-based vehicular networking [11]. This report collects the ongoing worldwide V2X standardization efforts aiming to introduce IPv6 in V2X communications and contains related applications and services. The document also reports on IPv6 transition strategies for vehicular communications and describes several concrete use cases in which the application of IPv6 could pose significant benefits to the system.

The IETF document [41] presents an up-to-date introduction and analysis of the use of IPv6 in Intelligent Transportation Systems (ITS) for vehicular networking. The main focus of the work is on the communication scenarios of V2V and V2I/I2V. The document first explains the use cases and requirements of C-ITS networking, then conducts a gap analysis of current IPv6 protocols (e.g., IPv6 Neighbor Discovery, Mobility Management, and Security & Privacy) in the context of IPv6-based vehicular networks. The analysis aims to identify the challenges and opportunities for using IPv6 in vehicular networks and the potential benefits for ITS.

Our current study contains the most recent authored papers on V2X systems in which IPv6 is also a key component. Our survey is broad in scope and does not only focus on specific technical concerns or feature areas of IPv6 in V2X. In the following sections, we list and briefly present V2X functional extensions and other proposals relevant to IPv6 communications in the vehicular domain. We classify the relevant articles into focus groups, and review recent works seeking to merge V2X and IPv6. We illustrate the core concepts and benefits of each of the surveyed articles.

4.2 Focus Group #1: IPv6 over IEEE WAVE

The Institute of Electrical and Electronics Engineers (IEEE) family of standards for Wireless Access in Vehicular Environment (WAVE) establishes an architecture and a supplementary standardized collection of services and interfaces that allow for secure V2I and V2V wireless communications. In addition, IEEE WAVE specifies the management structure, communication model security protocols, and architecture in vehicular environments [6]. Moreover, this standard is now regarded as the most promising technology for vehicular networks. Its goal is to promote compatibility and reliable safety communications in the vehicle environment [27].

4.2.1 IPv6 Operation for WAVE-Wireless Access in Vehicular Environments.

In the paper [42], the authors analyze IPv6 operation as defined in the IEEE 1609 family of specifications for WAVE networks and recognize areas where IPv6 procedures for WAVE networks are unclear. Never less, the author proposes a series of additional suggestions to allow optimal IPv6 service in WAVE networks and identifies the problems that have so far been left unresolved in terms of IPv6 function for WAVE. According to the authors, TCP is not often used in VANETs, leaving UDP the only feasible option inside the standard IPv6 stack. There are also technological explanations for why TCP may be a less suitable alternative for the vehicle network.

4.2.2 A Vehicular Mobility Management Scheme for a Shared-Prefix Model Over IEEE WAVE IPv6 Network.

In paper [43], the authors propose a vehicle mobility management technique using IEEE Wireless Access in Vehicular Environment (WAVE) IPv6 networks with a share-prefix architecture. This architecture includes vehicular mobility management neighbor discovery protocol (VMM-NDP) that is utilized for network attachment and handover operations, which manages route changes caused by changing serving Roadside Units (RSUs) within a shared prefix domain. Also, it conceals the IPv6 address change to Correspondent Nodes (CNs) by retaining the prior IPv6 address of the current vehicle is changed owing to the vehicle's relocation into a new shared domain.

Moreover, the authors of this paper noted issues with the present IPWAVE draft [43] of vehicular mobility management and conducted a comparative examination of their architecture to existing mobility architectures. The ns-3 (Network Simulator 3) [71] with its WAVE model library was applied to evaluate the proposed vehicle mobility management method. In conclusion, before the handover, the vehicle gets packets without loss. However, the disjoint scenario has considerable packet loss since RSU coverage does not overlap.

4.3 Focus Group #2: IPv6 over IEEE 802.11-OCB

Since the end of 2012, the Institute of Electrical and Electronics Engineers (IEEE) 802.11p modification has been part of IEEE 802.11 standard. It defines technical properties such as the usage of the 5.9 GHz bandwidth a 10 MHz channel and a novel operating mode to which all 802.11p compatible devices shall be set the Outside Context of Basic Service Set (OCB) mode. Moreover, the OCB mode mentioned in the previous sections, does not require authorization or identification, and the only parameters to configure are the channel bandwidth and central channel frequency [28].

4.3.1 Using IPv6 protocol in V2X networks based on IEEE 802.11-OCB mode of operation.

The paper [28], outlines the subject of using the IPv6 protocol on IEEE 802.11-OCB-based wireless networks. Furthermore, the authors discuss wireless network specifics and IP connectivity in V2X networks, emphasizing the layering and chosen IPv6 protocol properties. As a result, the IPv6 protocol, with just a few limitations, enables connectivity between nodes within a domain of each other over a monocular IEEE 802.11-OCB connection with minor modifications to the current protocol stack.

4.3.2 IPv6 Vehicular Communications over IEEE 802.11-OCB Wireless Link.

In this paper [29], the author proposes a possible IPv6 vehicular connectivity implementation using IEEE 802.11-OCB mode. As a result, the author discovered that the IPv6 link-local address was not configured automatically. The IPv6 Network Discovery (ND) protocol was either not operating or running automatically in standard protocol stacks.

4.4 Focus Group #3: IPv6 over GeoNetworking

GeoNetworking, as mentioned above, it is a network layer protocol that enables mobile ad hoc communication using wireless technologies (e.g., ITS-G5). It allows cellular connectivity without the requirement for a coordinating network. Moreover, GeoNetworking is a connectionless and completely dispersed network that operates on ad hoc network ideas with sporadic connectivity [44].

4.4.1 GeoNet: A project Enabling Active Safety and IPv6 Vehicular Applications.

In paper [45], the authors aim to introduce a reference specification for a geographic addressing and routing protocol with IPv6 compatibility that allows sending safety signals between vehicles and between vehicles and roadside facilities within a given destination location, which is called Geographic addressing and routing for vehicular communications (GeoNet). Thus, GeoNet's purpose was to develop and evaluate a networking framework as a discrete software module that could be integrated into Cooperative Systems. In conclusion, this project helped to establish the ETSI GeoNetworking standards and allowed clear IP communication between a vehicle and the infrastructure, also if distribution must be jumped through multiple vehicles or cached along the way.

4.4.2 IPv6 support for VANET with geographical routing.

In paper [46], the authors introduce a new method for effectively running IPv6 over VANET with geographical routing mechanisms, such as in the case of Car-to-Car Communication Consortium C2C-CC environments (CAR 2 CAR, 2021). Moreover, the authors proposed a scheme that runs IPv6 over VANET, which allows for effective IP setup and IP packet distribution without link-scope multicast. Vehicles can set up an IPv6 address at the global level and use it to connect with peers on and off the VANET. As a result, the solution uses inherent location control capabilities to carry out simple IPv6 protocols, including Neighbour Discovery and Stateless Address Autoconfiguration.

4.4.3 Experimental evaluation of an open-source implementation of IPv6 GeoNetworking in VANETs.

In paper [47], the authors explain CarGeo6, an open-source implementation of the IPv6 Geo Networking capability of the ITS station reference architecture, dependent on the Geo Net European Project output. Furthermore, the authors describe the CarGeo6 validation process and network efficiency assessment and compare these findings with Geo Net results. The authors attempted to analyze certain deployment efficiency factors, such as UDP's latency and packet processing ratio. The review of the findings revealed specific efficiency problems that could be improved by implementing certain extensions, such as the IP Next Hop cache to reduce latency and multi-hop beaconing to increase the efficiency of the multi-hope situation.

4.4.4 Real-vehicle integration of driver support application with IPv6 GeoNetworking.

In this paper [48], the authors design and implement an ITS network comprising two entities: an ITS server core and clients in vehicles that use IPv6 Geo-Networking, a geographical addressing and routing system created as part of the Geo-Net project [49]. Since the author's application promotes practical use case scenarios, he incorporated it into INRIA's vehicular platform. As a result, the system was incorporated into an outdoor field research area and worked successfully in practical cases as the Geo-Net project's final demonstration at INRIA.

4.4.5 Geographical information extension for IPv6: application to VANET.

In paper [50], the authors investigate and evaluate various options for enhancing IPv6 with geographical information. The paper's main challenge is incorporating geographical location into the existing IP architecture. However, to complete this challenge, the author investigated four major solutions: application layer expansion, IPv6 utilizing a sender-oriented protocol, IPv6 using a receiver-oriented routing protocol, and solely geographically based.

4.5 Focus Group #4: IPv6 support using NEMO

RFC 5177 defines Network Mobility (NEMO) [51] Internet standards track protocol. The protocol ensures that every node in a mobile network maintains its session while the network traverses, as a whole unit, changing its point of connection to the Internet and hence its reachability in the topology. NEMO comprises one or more IP subnets linked to the Internet [52].

4.5.1 Securing Vehicular IPv6 Communications.

In the article [53], the authors' work focuses on a particular scenario of vehicle-to-infrastructure connectivity, even though the network model discussed provides a V2V context.

Moreover, the authors' discussion depends on IPv6 technologies such as Internet Key Exchange protocol (IKEv2) and Internet Protocol security (IPsec) to support secure connectivity channels between a mobile router, that connects user and on-board devices and the accessibility, which is situated on the infrastructure side in a connected remote point. The paper's proposed paradigm focuses on maintaining IPv6 continuity for in-vehicle nodes via Network Mobility basic support (NEMO). The findings show that using the security proposal does not trigger a significant network overload. Because of the increased packet transfer times and the extra control details in IPv6 packets, there is just a slight efficiency loss as the traffic volume is boosted to make the most of the network.

4.5.2 Towards seamless inter-technology handovers in vehicular IPv6 communications.

In this paper [54], the author proposes an instantiation of the ISO/ETSI reference architecture for vehicular cooperative systems by implementing a real vehicular network based on IPv6 and NEMO's mobility infrastructure with Multiple Care-of Addresses Registration (MCoA) support. As a result, the tests show that the combination of NEMO/MCoA/802.21 MIH (Media Independence Handovers) system inside a vehicular communication stack can provide continuous connectivities during handovers while drastically reducing the time required for this process.

4.5.3 Continuous IPv6 Communications in a Vehicular Networking Stack for Current and Future ITS Services.

In paper [55], the authors describe a vehicular networking connectivity stack dependent on the well-known IPv6 protocol that adheres to current ISO/ETSI trends toward a popular ITS connectivity architecture while also offering modern extensions for handover and protection support. Furthermore, the primary goal in designing this stack was to provide integrated control of IPv6 mobility; the proposal is built on NEMO to enable future point of connection improvements at the IPv6 level. Still, it also includes an authentication/authorization system to automate access to protect domains and expand functionality from supporting handovers.

4.5.4 Car-to-Car and Car-to-infrastructure communication system based on NEMO and MANET in IPv6.

In paper [56], the authors discuss recent progress made by the IETF and NEMO in supporting IPv6 and its associated protocols. They also emphasize the need for the data exchange between vehicle and infrastructure and between vehicles, to be Internet-based and use IPv6 protocols. Moreover, the authors have examined the essential functional needs of the IPv6 communication system for ITS, and the purpose of the NEMO WG is to provide network mobility support to allow the complete IPv6 network to alter its point of attachment to the Internet topology. Following the presentation of the experimental framework for integrated communications, a test was performed utilizing the 4G access cube, a Linux MIPS Box from 4G Systems, and another test for V2V communications based on ad hoc networking. Furthermore, this project aims to create networks that can self-organize themselves with moving vehicles. In conclusion, IPv6 is the underlying communication protocol that will be used in ITS applications. The IPv6-associated concepts of NEMO, ad-hoc networking, and other technologies match the ITS communication system architecture requirements.

4.6 Focus Group #5: IPv6 Moving Object Networking (ipmon)

The ipmon was an IETF Birds of a Feather (BOF) session in late 2022, an informal conversation regarding a specific issue of interest to the Internet Engineering Task Force community. The BOF was declined, but planned activities proposed there were partly imported into the IPv6 Maintenance (6man) WG.

In case of support, the (ipmon)-defined [57] working group will focus on V2X use cases where IPv6 is well-suited as a networking technology and will build IPv6-based solutions to provide fast and encrypted communication between moving items and stationary systems. The key deliverables of this group will be IETF documents that define the procedures for transmitting IPv6 datagrams over either 3GPP 5G V2X or IEEE 802.11bd V2X. The already available draft documents are introduced in this focus group.

4.6.1 Vehicular Neighbor Discovery for IP-Based Vehicular Networks.

This IETF draft document [58] defines Vehicular Neighbor Discovery (VND) as an IPv6 ND extension for IP-based vehicular networks. To improve operational efficiency and save wireless bandwidth and vehicle energy, the authors propose a multi-hop Duplicate Address Detection (DAD) technique and an improved Address Registration. Furthermore, three additional neighbor discovery options are specified to advertise network prefixes and services within a vehicle.

4.6.2 Vehicular Mobility Management for IP-Based Vehicular Networks.

This document [59] defines a design for Vehicle Mobility Management (VMM) in IP-based vehicular networks. This IETF draft aims to provide an efficient mobility management system to facilitate V2X communications on the road. The VMM uses the mobility information and trajectory of each vehicle registered in the vehicular cloud's Traffic Control Center (TCC). Moreover, it can offer a moving car a proactive and smooth handoff as it moves along its trajectory.

4.6.3 Basic Support for Security and Privacy in IP-Based Vehicular Networks.

When implementing IP-based in self-driving situations, data interchange between self-driving vehicles is crucial to vehicle safety since received data from other vehicles may be utilized as inputs for vehicle operations. For that, this document [60] addresses potential security threats and privacy concerns in IPWAVE. Also, it suggests defenses for such attacks and weaknesses.

4.6.4 Context-Aware Navigation Protocol for IP-Based Vehicular Networks.

This document [61] presents a Context-Aware Navigation Protocol (CNP) for IP-based vehicular networks that would allow vehicles on road infrastructures to navigate cooperatively. The CNP protocol employs an IPv6 Neighbor Discovery (ND) option to send driving information. However, CNP attempts to improve driving safety by utilizing a lightweight method of transmitting driving information.

4.6.5 Service and Neighbor Vehicle Discovery in IPv6-Based Vehicular Networks.

This document [62] demonstrates using Domain Name System (DNS) resolution logic to discover a neighbor vehicle or the appropriate services. In addition, the authors raise two concerns related to IPv6 communication between neighbor vehicles and between vehicles and servers. As a result, a DNS Service Discovery and Multicast DNS (DNS-SD/mDNS)-based solution was provided to solve these issues. Also, IPv6 ND's can be used in ITS in conjunction with DNS-SD/mDNS to send certain needed information.

4.6.6 DNS Name Autoconfiguration for Internet-of-Things Devices in IP-Based Vehicular Networks.

A DNS Name Autoconfiguration (DNSNA) protocol was presented in this document [63] for the global DNS names of Internet of Things (IoT) devices in IP-based vehicular networks. As a result, in wired and wireless networks, the DNS name of an IoT device can be autoconfigured with the device's model information. IoT users on the Internet may quickly determine each device in a network for monitoring and remote-control.

4.7 Focus Group #6: Other IPv6 extensions for VANETs

Several IPv6 extensions have been proposed and implemented for VANETs. These extensions are designed to address the unique challenges of VANETs, such as mobility, low power, scalability, and efficient routing of packets. Moreover, these extensions are also proposed to improve the performance and security of VANETs.

4.7.1 eHealth Service Support in Future IPv6 Vehicular Networks.

In paper [64], the authors propose combining vehicular and eHealth testbeds and a lightweight auto-configuration approach built on a DHCPv6 extension to support IPv6 compatibility with a small number of messages. Moreover, the authors reflect on incorporating eHealth in V2I environments, encouraging Internet usage from vehicle settings to spread health-related data. Experimentation shows that eHealth-specific data can be transmitted over IPv6 from a vehicular environment using an experimental IPv6 implementation over High-Speed Packet Access (HSPA) in the beyond 3G era of mobile communications.

4.7.2 Application of IPv6 multicast to VANET.

In paper [65], the authors investigate and analyze the possibilities for incorporating an IPv6 multicast mechanism in Vehicular Ad hoc Networks (VANET). Moreover, the authors propose encoding GPS coordinates into IPv6 multicast addresses and using digital maps to map multicast addresses to dedicate locations. Consequently, when using their proposed software, appropriate delays are indicated, and streamlined delays are demonstrated when using the static multicast daemon.

4.7.3 A study of IP-based vehicular gateway with IPv6.

In this paper [66], the authors introduce the plan and deployment of an IPv6-based in-vehicle gateway (IVG) for end-to-end connectivity between an IPv6-based controller area network (CAN) unit and an Ethernet-based segment. Furthermore, the following characteristics of this architecture and deployments: 1) different in-vehicle bus nodes will seamlessly link to the IPv6 internet and exchange data through interconnection; 2) each vehicle node is allocated a distinct IPv6 address.

As a result, the terminal monitor will use the unique IPv6 address to reach the in-vehicle CAN node, send instructions, request data, and perform remote diagnostics on IP-based vehicles.

4.7.4 IPv6-based vehicular cloud networking.

In this paper [70], the authors suggest an IPv6-based vehicular cloud network (VCN). Information acquisition is accomplished by IP-based unicast rather than content-centric broadcasting to lower the cost of content acquisition. Moreover, a modern address structure is suggested to connect an IP address and a type of content and use this modern address (the contents can be obtained in a unicast manner from the closest vehicular cloud member). Also, the authors have proposed a specific scheme for this purpose.

Consequently, after the scheme has been tested and assessed, it demonstrates that it efficiently decreases the cost of content acquisition.

4.7.5 Research on IPv6 address configuration for VANET.

In article [67], the authors suggest an IPv6 setup scheme for VANETs. In the system, each Access Point (AP) has its own address space and the authority to delegate an IPv6 address to an On-board Unit (OBU). The address setup task is therefore spread through all APs in a VANET. In addition, the authors suggest an address recovery algorithm in which an AP will restore IPv6 address services published by OBUs in a timely and efficient manner. As a result, the proposed scheme lowers the cost of address configuration, shortens the latency in address configuration, and increases the performance rate of address configuration.

4.7.6 Cellular V2X IPv6 Transaction Support via Global IP Address.

This technical report [68] contains all of the Application Programmable Interfaces (APIs) required for on-board Unit (OBU) and Roadside Unit (RSU) implementations of such IPv6 global sessions. Furthermore, this study explains how to create the WAVE Router Advertisement (WRA) on the RSU and how the OBU must enable general IPv6 internet access via the RSU.

4.7.7 Cross-layered Architecture for Securing IPv6 ITS Communication: Example of Pseudonym Change.

In paper [69], the authors provide an ITS station reference design recently created by ETSI TC ITS and ISO TC204 WG16. In addition, the authors suggest a Service Access Point definition for securing Cooperative ITS communication using IPv6 by developing generic instructions for activating/deactivating IPv6 security services; and by developing generic commands for requesting atomic security operations. Moreover, the authors also illustrate an example of how the suggested generic instructions are utilized in the pseudonym change. Lastly, this study contributes to the ISO/ETSI ITS station reference architectural standardization, and the example in this study serves as a starting point for critically considering the cost of the pseudonym change at the IPv6 layer.

Table 1. Details of the surveyed papers

1st Group		**IPv6 over IEEE WAVE**		
Reference	Topic	Focus of evaluation	Evaluation parameters	Main results
[42]	-Analyzing IPv6 operation defined in the IEEE 1609 family of specifications for WAVE networks.	-Collects areas where IPv6 procedures for WAVE networks are not well investigated, lists issues, and analyses the main challenges of providing IPv6 for WAVE networks.	-IPv6 link model. -IPv6 addressing model. -WAVE interface in Link model. -Neighbor asymmetry.	-The authors have identified the problems that have been left unresolved in terms of the IPv6 function for WAVE.
[43]	-A vehicle mobility management technique with a share-prefix architecture.	-Describes the issue and offers a partial solution based on the specifications.	-Enhances the effectiveness of wireless communication. - Supports pseudonym.	-Before the handover, the vehicle gets packets without any loss. However, there is considerable packet loss in the disjoint scenario.

2nd Group		**IPv6 over IEEE 802.11-OCB**		
Reference	Topic	Focus of evaluation	Evaluation parameters	Main results
[28]	-Outlines the use of the IPv6 protocol on IEEE 802.11-OCB-based wireless networks.	-Terminology description used in V2X networks and the IPv6 protocol properties in greater depth.	-Forming stable Interface ID. -Creating subnet structure in V2X.	-IPv6 protocol enables connectivity between nodes within a domain of each other over a monocular IEEE 802.11-OCB connection with minor modifications to the current protocol stack.
[29],	-Suggestion for a possible IPv6 vehicular connectivity implementation	-The system architecture of IPv6 vehicular communications over IEEE 802.11-OCB mode to aid IPv6 adoption in vehicular communications.	- Implementation alternative for the IPv6 over IEEE 802.11-OCB.	-The author discovered that the IPv6 link-local address wasn't configured automatically, and the IPv6 Network Discovery (ND) protocol was either not operating or running automatically in standard protocol stacks.

3rd Group		**IPv6 over GeoNetworking**		
Reference	Topic	Focus of evaluation	Evaluation parameters	Main results
[45]	-Introduce reference specification for geographic addressing.	-Describe the problem and provide a solution based on requirements.	-Impact of traditional attacks on vehicles operating IPv6 GeoNetworking.	-Establishing the ETSI GeoNetworking standards by allowing clear IP communication.
[46]	-New method for effectively running IPv6 over VANET.	-C2C-CC architecture as a reference frame, using IPv6 operation without relying on link-scope.	-IPv6 using geographical routing mechanisms. -Neighbor Discovery.	-Inherent location management capabilities to carry out basic IPv6 protocols.
[50]	-Evaluation of various options for enhancing IPv6 with geographical info.	-Geographical addressing information extension for IPv6	-Decreasing the dependency. -IPv6 using geographical-based protocol	-Application layer expansion, IPv6 utilizing a sender-oriented protocol, uses a receiver-oriented routing protocol.

[47]	-Implementation of IPv6 Geo Net capability of ITS station.	-Reporting the validation procedure and the network performance evaluation of CarGeo6.	-Evaluating the latency on IPv6 hosts connected to a mobile router (MR).	-Specific efficiency problems that could be improved by implementing certain extensions to reduce latency.
[48]	-Implementing an ITS Network that uses IPv6 Geo-Networking	-Establishing a geographical addressing and routing mechanism in the GeoNet project.	-Testing multi-hop communication in VANET. -Demonstrating the efficiency of incorporating the ITS functionality on top of IPv6 GeoNetworking.	-The system was incorporated into an outdoor field research area and worked successfully in practical cases as the Geo-Net project's final demonstration at INRIA.

4th Group		**IPv6 support using NEMO**		
Reference	Topic	Focus of evaluation	Evaluation parameters	Main results
[53]	-Focusing on the security of IPv6 in the particular case of V2I communications.	-Experimental evaluation of the proposal using networking technology focused on base network efficiency and handover.	-Handover time operation.	-No significant overload in the network is generated by the security proposed in the paper.
[54]	-Suggestion of instantiating the ISO/ETSI reference architecture by implementing a real vehicular network based on IPv6.	-Handover time and characteristics.	-Network efficiency with a particular emphasis on handover time.	-The combination of NEMO/MCoA/802.21 MIH system can provide continuous connectivity during handovers while drastically reducing the time required for this process.
[55]	-Description of a vehicular networking stack based on IPv6 protocol that adheres to current ESO/ETSI trends.	-New extensions for enhancing security and handover assistance and integrating of IETF protocols.	-IPv6 feasibility to minimize handover latency.	-An authentication/authorization system to automate access to protect domains and expand functionality from supporting handovers.
[56]	-Description of the recent work at the IETF and NEMO	-Experimental framework for integrated communications	- Creating networks that can self-organize themselves with moving vehicles	-The IPv6-associated concepts of NEMO, ad-hoc networking, and other technologies match the ITS communication system architecture requirements.

5th Group		**IPv6 Moving Object Networking (ipmon)**		
Reference	Topic	Focus of evaluation	Evaluation parameters	Main results
[58]	-Defining (VND) as an IPv6 ND extension for IP-based vehicular networks.	-Multihop Duplicate Address Detection (DAD) technique and an improved Address Registration are used to improve efficiency.	-Neighbor Discovery -Duplicate address detection	-An efficient mobility management design is also provided to facilitate efficient V2X communications.
[59]	-Defining a design for Vehicle Mobility Management (VMM) in IP-based vehicular networks.	-Provide an efficient mobility management system to facilitate V2X communications on the road.	-Mobility management	-VMM can offer a moving vehicle with a proactive and smooth handoff as it moves along its trajectory.
[60]	-Addressing potential security threats and privacy concerns in IPWAVE.	-Suggests defense for such attacks and weaknesses.	-Security and privacy	
[61]	-Context-Aware Navigation Protocol (CNP) for IP-based vehicular networks.	-The CNP protocol employs an IPv6 Neighbor Discovery (ND) option, which sends driving information.	-Neighbor Discovery	-CNP attempts to improve driving safety by utilizing a lightweight method of transmitting driving information.

[62]	-Demonstrating how to use Domain Name System (DNS) resolution logic to discover a neighbor vehicle.	-Two concerns were raised related to IPv6 communication between the neighbor vehicle and between the vehicle and server	-Neighbor vehicle -Link layer address	- DNS Service Discovery and Multicast DNS (DNS-SD/mDNS)-based solution was provided to solve these issues. IPv6 ND's can also be used in ITS in conjunction with DNS-SD/mDNS to send information.
[63]	-Presenting a DNS Name Autoconfiguration (DNSNA) protocol.	-An IoT device autoconfiguration strategy based on device configuration and DNS search list.	-Network Discovery -Router Advertisement -Stateless Address Autoconfiguration	-The DNS name of an IoT device can be autoconfigured with the device's model information. IoT users on the Internet may quickly determine each device in a network for monitoring and remote control.

6th Group		Other IPv6 extensions for VANETs		
Reference	Topic	Focus of evaluation	Evaluation parameters	Main results
[65]	-Analyzing the possibilities for incorporating an IPv6 multicast mechanisms	- Encoding GPS coordinates into IPv6 multicast addresses.	- Measuring the delay of multicast.	-Appropriate delays are indicated using easy the proposed software, and the static multicast routing daemon shows streamlined delays.
[67]	-Suggestion of an IPv6 setup scheme for VANET.	-Introducing an address recovery algorithm and testing the proposed scheme's results.	-CAC, HID, and the suggested scheme are tested.	-The scheme lowers the cost of address configuration, shortens the latency in address configuration, and increases the performance rate of address configuration.
[70]	-Suggestion of an IPv6-based vehicular cloud network (VCN) in which information acquisition is accomplished by IP-based unicast.	-New address structure to establish the relationship between an IP address and the contents, which can be acquired in a unicast manner from the nearest vehicular cloud member.	-Assessing the multimedia file-sharing service and matching the expense in this paper's scheme to the cost in another paper's current scheme.	-After the scheme has been tested and assessed, it demonstrates that it efficiently decreases the cost of content acquisition.
[66]	-Deployment of an IPv6-based in-vehicle gateway (IVG) for end-to-end connectivity.	-Evaluating the conversion of IPv4 to IPv6 and developing an address mapping system.	-A unique IPv6 address to reach the in-vehicle CAN node.	-Testing IPv6 address to reach the in-vehicle CAN node, send commands and request information and perform remote diagnostics on IP-based vehicles.
[64]	-Combination of vehicular and eHealth testbeds and a lightweight auto-configuration approach built on a DHCPv6 extension.	-Evaluate the IPv6 vehicular interface that incorporates eHealth sensors and allows for the transmission of collected health-related data.	-Comparing the throughput between IPv6 access point name (APN) with IPv4 APN for eHealth application in V2X.	-Experimentation shows that eHealth-specific data can be transmitted over IPv6 from a vehicular environment using an experimental IPv6 implementation over (HSPA).
[69]	-Suggesting a Service Access Point definition for securing C-ITS communication using IPv6.	-Developing generic instructions for activating/deactivating IPv6 security services.	-Illustrating an example of how the suggested generic instructions are utilized in the pseudonym change	-This study contributes to the ISO/ETSI ITS station reference architectural standardization.

V. Conclusion

We examined the current status of IPv6 integration in V2X networks in-depth, focusing on the supported IPv6 features. IPv6 allows IP-enabled technologies, applications, and services to be seamlessly implemented and used in vehicular communications. Moreover, it was also claimed that IPv6 has many benefits that resolve essential needs of collaborative vehicular communication, such as a broad address space due to the depletion of IPv4 address space, affecting internet continuity growth. IPv6 only should be encouraged to be the primary IP-based solution for V2X, with other transitions seen as supplemental [9]. In addition, this paper also presents details on existing standards of V2X-related IPv6 supporting schemes (IEEE WAVE networking layer, IPv6 over IEEE 802.11-OCB, and ETSI GN6ASL). Our survey concluded that we still should consider IPv6 as the primary driver of the global network connectivity in V2X to provide the reachability of Internet resources. Several authors focused on using IPv6 as the primary communication protocol instead of the dedicated protocol developed specifically for each wireless communication system in the cooperative ITS domain. The main proposal is to consider IPv6 a universal protocol even in V2X wireless communications. Available results in the literature proposed multiple modifications, missing features, and protocol improvements to cope with the requirements of V2X. These papers analyzed the existing issues of IPv6 when it is used in V2X, including security. Despite these results, IP(v6) communication is still considered outside of the scope of safety V2X applications but started to gain momentum in other use cases due to the increasing proliferation of 5G technologies and C-V2X.

AUTHOR CONTRIBUTIONS

H. Farran: Conceptualization, Theoretical analysis, Writing.

L. Bokor: Supervision, Review and editing.

DISCLOSURE STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Rheological characterisation of bituminous binder blends for the design of asphalt mixes with high recycled asphalt content

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Abstract: Reclaimed asphalt pavement (RAP) is gained from road reconstructions; however, its usage is less optimised in Hungary and neighbouring regions, since on the project level the proportion of RAP in the asphalt mixes is only 10-15%. This is less than the recommended level in other EU countries. The higher usage of RAP provides economic and environmental advantages, decreasing the need for new materials, the transport cost, and the carbon footprint. The composition of the resultant bituminous binder blend is a critical element in the asphalt mix design with high RA content. This paper discusses the design of the resultant bituminous binder blend to provide performance and compliance characterisation. This paper also presents the complex rheological analysis of the base bitumen, the bitumen extracted from the RA and the bituminous binder blend, applying the dynamic shear rheometer (DSR) device. It was shown that for paving grade bitumen (B), polymer modified bitumen (PmB) and rubber modified bitumen (GmB), the addition of higher proportions of RA content is possible without compromising on the performance of the binder blend. With a carefully chosen paving grade bitumen it is possible to utilise up to 40% RA content. For the polymer modified bitumen, the limit of the RA content is 20%. For the rubber modified bitumen, the various proportions of RA contents showed no or negligible changes in the characteristics of the bitumen and the RA content can reach 30% in this case.

Keywords: recycled asphalt pavement; dynamic shear rheometer; binder blend characterisation; Black diagram

I. INTRODUCTION

Reclaimed asphalt pavement (RAP) is gained from road reconstructions; however, its usage is less optimised in Hungary and neighbouring regions, since on project level the proportion of RAP in the asphalt mixes is only 10-15%, that is less, than the recommended level in other EU countries [1]. The higher usage of RAP provides economic and environmental advantages, decreasing the need for new materials, the transport cost, and the carbon footprint, moreover, promoting ecological issues. For example, in the reconstruction of Motorway M1 (Budapest – Vienna) the usage of RAP will be a real challenge. The authors have analysed the possibilities for producing asphalt mixes of high RAP content through the development of the production plant in a recent research and development project. However, there was still a need for dealing with the problems of the asphalt mix design and stockpile management in the production of asphalt with high RAP content. Previous studies [2, 3] have demonstrated that RAP may exhibit variability, therefore the characterisation of RA is necessary, especially for high RAP asphalt mixes.

The volumetric design of an asphalt mix of high recycled asphalt (RA) content is the same as the mix design procedure of any other asphalt mix [4, 5]. However, there is a critical element in the mix design, the composition of the resultant bituminous binder blend should be considered when designing a mix with a high RA content as part of the volumetric mix design [6]. Because of the ageing of the binder of the RA, there may be a need for the „rejuvenation” or „regeneration” of the binder of the RA by adding fresh bitumen and/or rejuvenator additives. This fact can be extremely important in case of a RA originating from older, intensely aged pavements or in case of adding a higher proportion of RA into the mix. Words like „rejuvenation" or „regeneration" can be misleading, since these additives can serve two goals; either the modification of the chemical content of the bitumen, or the modification of the performance and the compliance of the bitumen. This paper deals with the design of the resultant bituminous binder blend to provide the performance and the compliance and does not deal with the modification of the chemical content.

The predictive calculations of the performance and the compliance of the resultant bituminous binder blend are performed based on penetration [7], softening point [8], elastic recovery [9], or dynamic shear rheometer (DSR) viscosity. These tests are valid for a certain temperature or loading (frequency) point, and not necessarily consider the complex rheological characteristics of the bituminous binder blend, which is influenced by the required base bitumen and the bitumen extracted from the RA.

This paper presents therefore the complex rheological analysis of the base bitumen, the bitumen extracted from the RA and the bituminous binder blend, using the DSR device. Performing the provided test series and analysis may not be practical for the daily routine in the factory production control at an asphalt production plant, nevertheless, the scientific results presented are critical for understanding the overall performance of the bituminous binder blends.

II. Preparation of bituminous binder blends

For the analysis described in this paper, normal paving grade bitumens, polymer modified bitumens and rubber modified bitumens have been mixed with the aged binder extracted from RA in different mass proportions, based on a special procedural order. The extraction of the RA binder was performed according to standard test method MSZ EN 12697-3 [10]. The analysis of these blends in the present work has not included the traditionally required softening point and penetration tests, rather the values of the complex shear modulus, the phase angle and the complex viscosity have been determined applying the DSR device, representing the results on Black diagrams as described later. The procedural order was as follows:

- The approximately required quantity is cut from the bitumen and measured on a precision scale in a jar. After the measurement, the quantity of the bitumen in the jar is increased or decreased until the required amount of the prescribed blending proportion is reached with the required accuracy. This step is performed for both bitumens (the recycled and the fresh).
- The jar with the measured bitumen quantities is put into an oven at 170°C temperature for about 15 minutes.
- In the oven the blend is thoroughly remixed for 2 minutes using a spatula or an equivalent tool.
- The remixed bitumen is stored in the oven for a further 5-10 minutes to reach again 170°C temperature (the spatula may remain in the bituminous blend).
- The specimen is remixed again (no time required, a thorough 10-30 seconds mixing is recommended though) and in the oven the bitumen is poured into the specimen template forms. Two pieces of samples are made from each blend.
- The templates are heated to 170°C temperature as well to let the specimen extend properly, then they are removed from the oven to let cool down.
- After cooling, the surplus amount of bitumen is cleared away, entirely to the plane of the template form.
- The completed specimens are put into a refrigerator at 10°C temperature until the DSR measurements are performed.

III. Rheological characteristics determined by the dynamic shear rheometer (DSR)

1. The DSR device

The dynamic shear rheometer (DSR) is suitable for the testing of asphalt binders (**Fig. 1**). During the test, rheological parameters, like the complex shear modulus (G*) and the phase angle (δ) can be measured at a wide frequency and temperature range. These parameters are used for characterising

Figure 1. *Dynamic shear rheometer (DSR), Rheotest 4.3*

the viscous and elastic behaviour of the asphalt binder.

The complex shear modulus characterises the resistance to deformation of the material, in case of a sinusoidal shear stress loading as expressed by equation (1), where τ is the stress and γ is the strain.

$$G^* = \frac{\tau_{max} - \tau_{min}}{\gamma_{max} - \gamma_{min}} \quad (1)$$

The complex shear modulus as a rheological attribute consists of an elastic (recoverable) and a viscous (non-recoverable) component. The phase angle shows the relative quantities of viscous and elastic components, from a measurement point of view it is the phase difference between the applied stress and the resulted strain. Values of these two parameters for bituminous binders largely depends on the test temperature and the loading frequency. At high temperatures and low loading frequency binders behave as a viscous liquid with small recovery ability. On the contrary, at very low temperatures these binders behave as an elastic solid material, totally recovering from deformation. At normal pavement temperatures and traffic loading bitumens present both attributes (viscous liquid and elastic solid material), that is why they are rightly called viscoelastic materials.

The DSR test provides information on the behaviour of the bitumen by determining the complex modulus and the phase angle at a wide frequency and temperature range, relevant to the in-service pavement behaviour. **Fig. 2** demonstrates the relation of the two components of the viscoelastic behaviour.

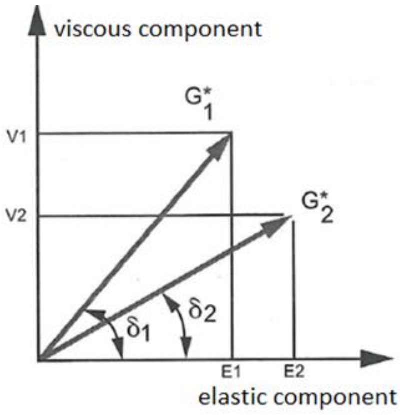

Figure 2. *The relation between the viscous and the elastic components of the viscoelastic*

In case of only viscous behaviour (G* has got no elastic component, coincidence with ordinate axis), $\delta = 90°$. In case of only elastic behaviour (G* has got no viscous component, coincidence with abscissa axis), $\delta = 0°$. The two complex modulus values on **Fig. 2** (G^*_1 and G^*_2) have the same absolute value representing the viscoelastic characteristics of two different bitumens. **Fig. 2.** indicates that only one parameter is not enough for describing the rheological characteristics of the bitumen, since the two bitumens are different, despite of their identical G* value. Bitumen marked „2" has a higher elastic component; therefore, the measured phase angle value is smaller [11].

Operation of the dynamic shear rheometer device is a rather simple task, there is no need for a serious professional education. The bitumen specimen for the test is prepared in a cylindrical shape using a silicone template form, although in certain cases putting the bitumen directly onto the plate is also permitted. The diameter of the template form can be 8 mm or 25 mm, depending on the test temperature and the expected value of the complex modulus or viscosity. Standard test method MSZ EN 14770 [12] recommends using 25 mm specimen diameter for measuring stiffnesses 1 kPa – 100 kPa (reached above about 40-50°C), and 8 mm specimen diameter for measuring stiffnesses 100 kPa – 10 MPa (reached at about 0-50°C). An advantage of the DSR test is that only a small amount of representative bitumen is required, in case of the 25 mm specimen, about 0,49 cm^3, and in case of the 8 mm specimen, about 0,1 cm^3. This is better than the material requirement of a penetration test or of a softening point test, since the DSR test can be performed when obtaining a very small amount of representative bitumen sample. The prepared specimen is placed between the parallel measurement plates of the rheometer (**Fig. 3**).

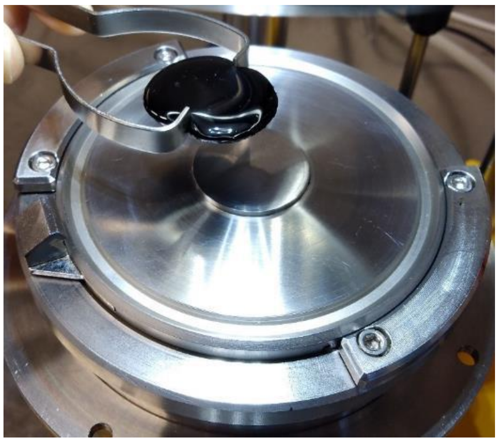

Figure 3. *Putting a 25 mm diameter specimen onto the DSR plate*

The lower plate is fixed, the other plate can be rotated for the oscillation loading. The proper gap distance shall be adjusted (in case of a 25 mm specimen it is 1,000 mm + 0,025-0,050 mm); the surplus bitumen pressed out shall be trimmed by a suitable tool like a metal spatula. During the measurement, the specimen is in a closed space that can be heated and cooled by a casing, and is loaded by a sinusoidal cyclic deformation, the so-called oscillation shear, at a controlled temperature, and the reaction stress is measured. It is worth performing strain-controlled measurements, since that guarantees a properly small deformation, so the bitumen can be tested under its viscoelastic domain. This is important because in this domain the connection between the stress and the strain is linear, the characteristics of the bitumen depend only on the time and temperature and does not depend on the magnitudes of the stress and strain. Performing this test, a lot of information about the bitumen can be acquired, since applying the DSR it is possible to perform measurements at different temperatures and at various frequencies.

2. DSR test parameters

DSR tests may be performed by existing standards MSZ EN 14770 [12], AASHTO T 315 [13] or AGPT-T192 [14]. For the temperature-frequency-sweep analysis an important step is to determine the shear strain amplitude. Former studies have proven that at 5% strain value the results are within the linear domain both in case of normal bitumen and in case of modified bitumen [15], therefore for the DSR tests presented in this paper 5% strain value was chosen.

The temperature-frequency-sweep analysis between 0°C and 70°C has been performed at the following parameters:

between 50-70°C

- 5% strain
- 50-60-70°C
- frequency values 0.1 - 0.1668 - 0.2783 - 0.4642 - 0.7743 - 1.292 - 2.154 - 3.594 - 5.995 - 10 Hz
- specimen diameter 25 mm
- specimen thickness 1.0 mm

between 0-50°C

- 5% strain
- 0-10-20-30-40°C (some measurements were possible only at the 30-40°C domain because of the stiffness of the bitumen)
- frequency values 0.1 - 0.1668 - 0.2783 - 0.4642 - 0.7743 - 1.292 - 2.154 - 3.594 - 5.995 – 10 Hz
- specimen diameter 8 mm
- specimen thickness 2.0 mm.

3. Presenting rheological data

The resulting data from the DSR tests shall be presented for the studies of rheological characteristics of road paving binders (both normal bitumens and polymer modified bitumens) in a useful and easily understandable way, providing a possibility for a simple comparison. Since the DSR test provides a large amount of data, their presentation is not necessarily an easy task.

A simple graphical presentation is the isochrone diagram or the isochrone curve. Such a graph shows the behaviour of the binder at a constant frequency or loading time. Isochrones are presented when plotting curves of a complex modulus (G*) or other viscoelastic functions obtained from a DSR test as a function of the temperature [16].

The isothermal plot or isotherm is a curve that presents the complex behaviour of the bitumen at a constant temperature. Isotherms are presented when plotting curves of a complex modulus (G*) obtained from a DSR test as a function of the frequency [16].

The Cole-Cole diagram presents the loss (viscous) modulus (G″) as a function of the stored (elastic) modulus (G′), containing the values of the complex modulus and the phase angle in an indirect way. The Cole-Cole diagram provides the possibility for presenting the viscoelastic characteristics of the bitumen without using the frequency and/or the temperature as a variable.

A Black diagram presents the absolute value of the complex modulus (G*) as a function of the phase angle (°). Similarly, to the Cole-Cole diagram, the Black diagram does not contain the frequency and the temperature, which makes possible to present all dynamic data on one diagram, without any time-temperature superposition calculation of the raw data (constructing a master curve). When the Black diagram shows a continuously decreasing curve, that means a useful indication of the equivalency of the time and the temperature. A not continuously decreasing curve suggests the lack of time-temperature superposition and is suitable for identifying polymer modified bitumens beside other deviations or changes in the composition of the bitumen [16].

The effect of the SBS modification (or any other modification) on the rheological parameters (the complex modulus and the phase angle) are presented on the Black diagram, eliminating the temperature and frequency dependency. Typical curves of

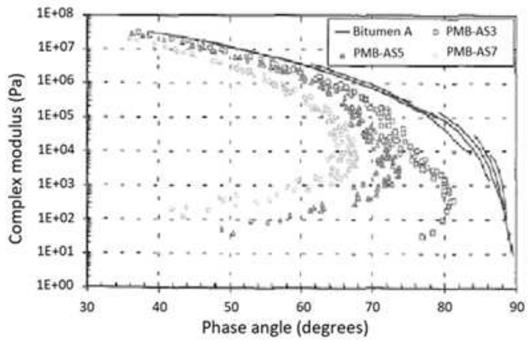

Figure 4. *Black diagram depending on the SBS modification*

bitumens with different SBS content are presented on **Fig. 4** [17].

For a lower polymer content (3%) the behaviour of the modified binder is rather resembles the behaviour of the base binder since the phase angle remains near to the value of 90° at high temperature low frequency. In case of a higher polymer content (5 and 7%) the characteristics of the base binder changes considerably since the phase angle significantly decreases and remains usually below the value of 70°.

The DSR may be utilised to run the binder fast characterization (BTSV) test and it was developed for fast characterization of bitumen and it could be used as a replacement to the softening point test [18]. The DSR can be used to perform the Grower-Rowe test, which is a method developed to characterize the susceptibility of a binder to cracking [19, 20]. The Multiple Stress Creep Recovery Test (MSCRT) is developed to determine the creep performance of asphalt binders using the DSR [21].

The BTSV, Glover-Rowe and MSCRT tests are developed to describe specific binder behaviour, such as high temperature creep or cracking potential. While they provide useful description of the binder for specific application, the overall complex behaviour of the binder can be assessed by the Black diagram. Therefore, this paper utilises this methodology to describe various binder blends.

4. Measuring complex viscosity and estimating complex viscosity of the bituminous binder blend

Test method AGPT-T193 [22] includes the design process of the viscosity of binder blends. A study by Austroads [23] recommended if the RA proportion of an asphalt mix is above 15%, the properties of the binder blend (consisting of RA binder, base binder and possibly rejuvenator additive) shall be determined as follows:

- Collect a representative sample of the RA
- Determine the binder content of the RA
- Extract the binder from a representative sample of the RA
- Determine the complex viscosity of the RA binder, the virgin binder and rejuvenator (where applicable) by using the DSR at 60°C and 1 rad/s
- Predict the viscosity of the binder blend according to AGPT-T193 [22]
- If the predicted viscosity is outside of the desired range for the design, adjust the proportion of the binder blend components iteratively to achieve the desired viscosity range of the final product.

The method has already been validated for Hungarian conditions [24].

The viscosity of virgin bitumens and bitumens extracted from RA were measured according to the method described before at 60°C, 1 rad/s, and the viscosity of the binder blends were estimated applying the calculation method. Following these steps, the blending process was validated by preparing bitumen blends in the laboratory and measuring their viscosity at the Budapest University of Technology and Economics, Department of Highway and Railway Engineering, Laboratory for Pavement Structures. The difference between the tested and calculated viscosity was calculated according to equation (2), where Δ is the difference and ν is the viscosity.

$$\Delta = \frac{|\nu_{tested} - \nu_{calculated}|}{\nu_{calculated}} \times 100 \qquad (2)$$

The results are presented in the next chapter.

IV. Analysis of binder blends of bitumens and RA originated bitumens

The bitumen samples were extracted (MSZ EN 12697-3) from asphalt samples collected from two RA sources as described later and the bituminous binder blends have been prepared according to the procedure mentioned above. Following this, the DSR temperature-frequency-sweep testing has been performed, bituminous binder blends of different RA content, characteristically 10-20-30-40%, has been prepared in the laboratory. The temperature-frequency-sweep testing of the base bitumen, the RA bitumen and the blend of these has been performed at the University of Győr, Laboratory for Road Construction and then Black diagrams have been created from the results. The next part of the paper summarises these results.

Three types of base bitumen have been used, an SBS modified bitumen PmB, a rubber modified bitumen GmB and the normal paving grade bitumen B, keeping these abbreviations in the paper. Two sources of RA binder were used in this study:

- Zsámbék 0/11 RA 0/8 T002 – denoted as Zs RA T002. The orignal asphalt mix was probably manufactured using polymer modified binder, which is based on anecdotal evidence. According to verbal information, this RA has been originated from a reconstruction of a high-speed road, therefore it can be reasonably assumed that the original asphalt mix had been produced using PmB.
- Körmend 0/11 RA 0/8 – denoted as K RA. The RA was obtained from the demolition of a temporary road used for the construction of a bridge structure. The in-service life of the road was two years.

1. MOL PmB 25/55-65 + MOL B 50/70 blends

To ensure a controlled check (validation) of the calculation method of the binder blend viscosity for the PmB type binder, first a MOL PmB 25/55-65 bitumen has been mixed at 10-20-30-40% proportions with a MOL B 50/70 road paving bitumen. Analysis of these blends helped in mapping the magnitude of the „thinning" effect of the road paving bitumen on the PmB. Based on the results in **Table 1**., it was established, that the above described viscosity calculation method is valid for the PmB type binder, since the difference between the calculated and the measured viscosity values have been very small, remaining under 10%.

Table 1. *Summary of tested and calculated viscosities for MOL PmB 25/55-65 + MOL B 50/70 bitumen blends*

B 50/70 % (in blend)	***Tested viscosity (Pa.s)***	***Calculated viscosity (Pa.s)***	***Difference (%)***
10	1 466	1 368	7
20	1 161	1 122	3
30	1 008	924	9
40	838	763	10
100% MOL B 50/70	261		
100% MOL PmB 25/55-65	1 674		

The temperature-frequency-sweep has been performed by the DSR device for the base bitumens as well as for binder blends with 10-20-30-40% proportions of MOL B 50/70 content, and their Black diagrams have been plotted as on **Fig. 5**. The Black diagram – as mentioned above – describes the behaviour of the bitumen or the blend at a wide temperature and frequency range, showing the connection between the complex modulus and the phase angle.

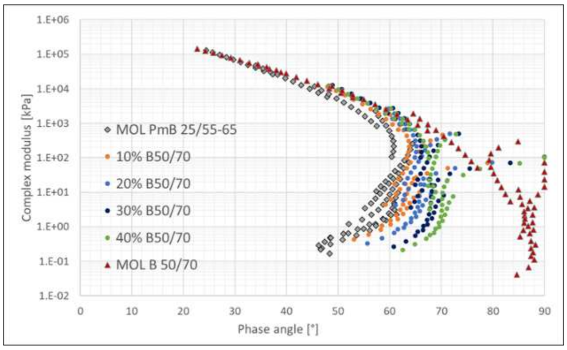

Figure 5. *Black diagrams of MOL PmB 25/55-65 + MOL B 50/70 blends*

As it has been described in the earlier sections, the PmB has got a low phase angle value at high temperature and low frequency values, that is clearly visible on **Fig. 5**. For blends with 10% and 20% B 50/70 content, it was observed that the characteristics of the basic PmB have not changed significantly from the point of view of the phase angle, although the curves have been slightly shifted downwards because of the lower complex modulus of the B 50/70. In case of blends with 30% and 40% B 50/70 content, the curves have been shifted further downwards, the complex modulus has decreased, and the phase angle has increased, indicating the increasing effect of the B 50/70. It is worth mentioning, that the characteristic PmB feature, the low phase angle, have remained dominant even for the 40% B 50/70 blending, which should have a significant „thinning" effect on the PmB.

2. Zs RA T002 + MOL B 70/100 blends

A relatively good agreement can be observed between the calculated and the measured viscosities when analysing the blends of an RA extracted bitumen originated from Zsámbék and the MOL B 70/100 base bitumen (**Table 2.**). Comparing to the analysis results in the previous chapter, here the difference between the calculated and the measured viscosities are higher, because of the presence of the bitumen extracted from the RA.

Table 2. *Summary of tested and calculated viscosities for Zs RA T002 + MOL B 70/100 bitumen blends*

RA % (in blend)	***Tested viscosity (Pa.s)***	***Calculated viscosity (Pa.s)***	***Difference (%)***
10	276	205	35
20	464	334	39
30	881	558	58
40	1 575	958	64
100% Zs RA T002	16 748		
100% MOL B 70/100	129		

In this section the authors have tried to analyse the changes in the characteristics of a relatively soft bitumen, the B 70/100, when blended with a stiffer bitumen extracted from RA. The viscosity of the B 50/70 bitumen was 261 Pa.s, and this value has been used for comparison. According to **Table 2.**, this viscosity value is close to the viscosity of the blend with the B 70/100 bitumen and 10-20% RA. This fact means that the viscosity of the harder RA bitumen can be decreased by adding a softer base bitumen to the blend, or the viscosity of a softer road paving bitumen can be increased by adding RA to the blend. These two statements have the same engineering meaning, although the aim of their utilisation is different. The Hungarian paving industry characteristically applies the B 50/70 bitumen, and a similar product can be created with the blend of the B 70/100 and the bitumen extracted from the RA.

Likewise in the previous section, the total temperature-frequency-sweep has been performed by the DSR device for the base bitumen (B 70/100) and the RA originated bitumen, as well as for binder blends with 10-20-30-40% proportions of RA bitumen content. Black diagrams are shown on **Fig. 6.**, including the curve of the B 50/70 bitumen for comparison. The observations have been the same as for the viscosities, the characteristics of blends with the B 70/100 and 10% RA as well as 20% RA bitumens are in good agreement with characteristics of the B 50/70 bitumen. It is worth mentioning that in these Black diagrams the typical shape of the PmB curves cannot be observed for the RA binder. A probable cause of this is the ageing and the degradation of the PmB during its life cycle.

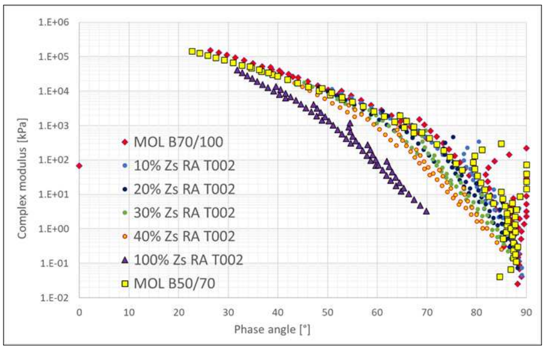

Figure 6. *Black diagrams of Zs RA T002 + MOL B 70/100 blends*

3. Zs RA T002 + MOL PmB 25/55-65 blends

In this series of analysis, the MOL PmB 25/55-65 has been blended by 10-20-30-40% proportion of the Zsámbék RA originated bitumen. Based on **Table 3**, there have been minimal differences between the calculated and the measured viscosities. For this blending series the temperature-frequency sweep has been performed as well, the relevant Black diagrams are shown on **Fig. 7**.

Table 3. *Summary of tested and calculated viscosities for Zs RA T002 + MOL PmB 25/55-65 bitumen blends*

RA % (in blend)	***Tested viscosity (Pa.s)***	***Calculated viscosity (Pa.s)***	***Difference (%)***
10	2 360	2 142	10
20	3 178	2 757	15
30	4 112	3 569	15
40	5 597	4 649	20
100% Zs RA T002	16 748		
100% MOL PmB 25/55-65	1 674		

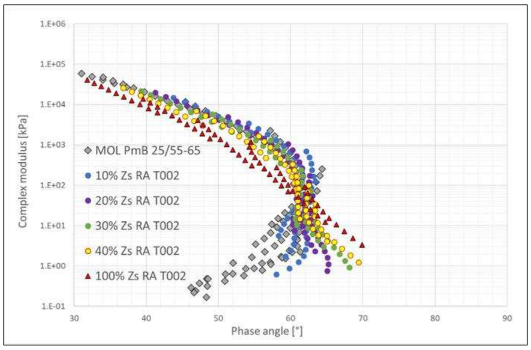

Figure 7. *Black diagrams of Zs RA T002 + MOL PmB 25/55-65 blends*

It can be observed, that in case of 30% and 40% RA contents, phase angles have started to increase at the high temperature and low frequency domain, although the phase angle values have remained still in the rather lower domain characterising PmB types, not exceeding the 70° value. This observation is valuable for the practical utilisation, since the 10% and 20% RA proportion in the PmB based blend has not indicated any significant changes. While in the domain of the 30% and 40% RA content the original characteristics of the PmB have not fully remained, the dilution into a normal paving bitumen still has not occurred.

To prove this statement, **Fig. 8.** has been plotted including the Black diagram of the OMV B 20/30 bitumen, that is one of the hardest road paving bitumen types available on the market nowadays. **Fig. 8.** proves the validity of the statement; however, there is a need for further research in this field when the practical utilisation requires more than 20% RA content in the blend when applying a PmB base bitumen.

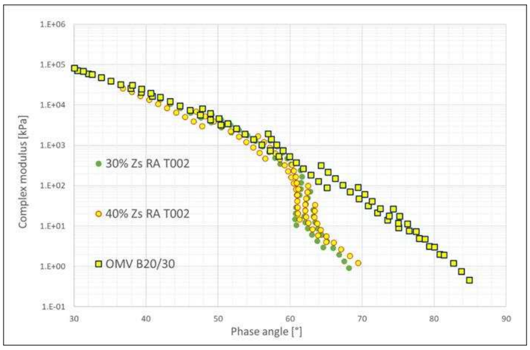

Figure 8. *Black diagrams of Zs RA T002 + MOL PmB 25/55-65 with 30% and 40% RA content blends, including the OMV B 20/30 blends*

4. Zs RA T002 + MOL PmB 45/80-65 blends

In this series of analysis, the MOL PmB 45/80-65 bitumen has been used instead of the MOL PmB 25/55-65 bitumen that is currently widely used in Hungary. The Hungarian practice has less utilised the MOL PmB 45/80-65 bitumen, nevertheless, the aim of this part of research has been whether it is possible to reach a performance similar to the blends of the MOL PmB 25/55-65 base bitumen containing bitumen extracted from RA. The proportion of the Zs RA T002 bitumen has been 10-20-30-40%, similarly to the previous series. The comparison table of the calculated and the measured viscosities shows a rather good agreement between the values, similarly to the case of the PmB 25/55-65 bitumen (**Table 4.**).

Table 4. *Summary of tested and calculated viscosities for Zs RA T002 + MOL PmB 45/80-65 bitumen blends*

RA % (in blend)	*Tested viscosity (Pa.s)*	*Calculated viscosity (Pa.s)*	*Difference (%)*
10	2 440	1 901	28
20	2 973	2 479	20
30	4 216	3 255	30
40	5 590	4 303	30
100% Zs RA T002	16 748		
100% MOL PmB 45/80-65	1 467		

For this blending series the relevant Black diagrams based on the temperature-frequency sweep are shown on **Fig. 9**.

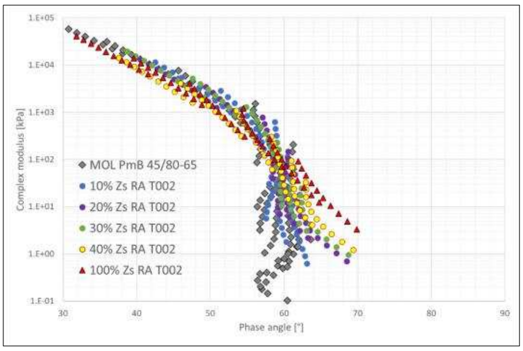

Figure 9. *Black diagrams of Zs RA T002 + MOL 45/80-65 bitumen blends*

It can be observed that even the 40% RA content has not significantly changed the features of the PmB 45/80-65 bitumen, regarding both the complex modulus and the phase angle. On **Fig. 10**. the Black diagram of the PmB 25/55-65 bitumen has been plotted as well; based on **Fig. 10** it can be stated, that both the PmB 45/80-65 bitumen and its 40% RA content blend have got significantly different curves compared to the PmB 25/55-65 bitumen.

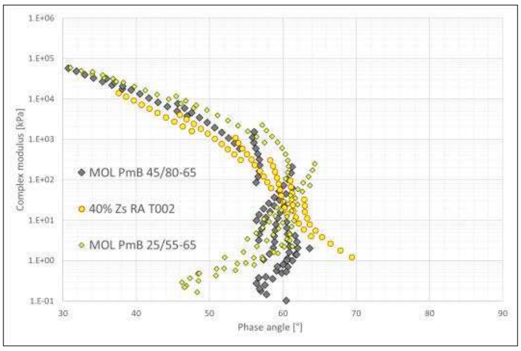

Figure 10. *Black diagrams of MOL PmB 45/80-65 + 40% RA blend, as well as of the MOL PmB 45/80-65 and the MOL PmB 25/55-65 bitumens*

5. Zs RA T002 + MOL GmB 45/80-55 blends

The rubber modified bitumen is interesting for the Hungarian road paving, therefore the next series of analysis has dealt with the blends of the rubber modified bitumen and the bitumen extracted from RA. The base bitumen used has been the MOL GmB 45/80-55, blended with the Zsámbék RA T002 extracted bitumen in 10-20-30-40% proportions. Rubber modified bitumens are normally characterised by their penetration and softening point similarly to the PmB grade. Although the rubber modified bitumens show similar characteristics to the PmB (as per the EN product standard), the rubber particles form a blend with its base bitumen in a different way. That may be the explanation of the weak correlation between the measured and the calculated viscosities (**Table 5**).

Table 5. *Summary of tested and calculated viscosities for Zs RA T002 + GmB 45/80-55 bitumen blends*

RA % (in blend)	*Tested viscosity (Pa.s)*	*Calculated viscosity (Pa.s)*	*Difference (%)*
10	3 045	2 079	46
20	4 321	2 685	61
30	6 031	3 488	73
40	7 411	4 561	62
100% Zs RA T002	16 748		
100% MOL GmB 45/80-55	1 333		

Interestingly, Black diagrams show a far better agreement than the viscosities. Based on **Fig. 11**, it can be observed, that the RA content has practically no effect on rheological characteristics of the base GmB 45/80-55, as their Black diagrams are almost fully overlapped. It can also be observed that the characteristics of the GmB 45/80-55 are not similar to the PmB bitumens described before. Although at the range of high temperature and low frequency, phase angles have remained under 80°, this still differs from the characteristics of the PmB 25/55-65, where phase angles have only slightly exceeded the 60° value. Another figure (**Fig. 12.**) has been plotted including the Black diagram of the OMV PmB 10/40-65 bitumen, since the characteristics of the GmB 45/80-65 has been found to be similar to this bitumen type.

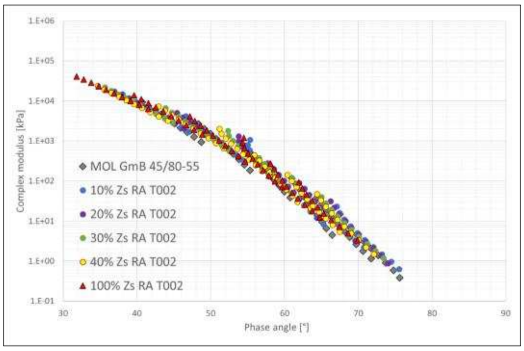

Figure 11. *Black diagrams of Zs RA T002 + GmB 45/80-55 blends*

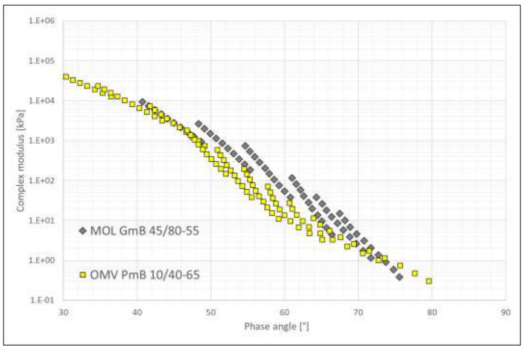

Figure 12. *Black diagrams of the GmB 45/80-55 and the OMV PmB 10/40-65 bitumens*

Table 6. *Summary of tested and calculated viscosities for Zs RA T002 + GmB 45/80-55 bitumen blends – repeated analysis*

RA % (in blend)	***Tested viscosity (Pa.s)***	***Calculated viscosity (Pa.s)***	***Difference (%)***
10	3 863	2 079	86
20	4 828	2 685	80
30	6 435	3 488	84
40	8 116	4 561	78
100% Zs RA T002	16 748		
100% MOL GmB 45/80-55	1 620		

Since there are only limited experiences in the Hungarian practice concerning the GmB 45/80-55 bitumen, it was intended to validate the first set of results presented beforehand. The test regime and analysis for the GmB have been repeated regarding both the viscosity (**Table 6.**) and the temperature-frequency sweep with its resulting Black diagram (**Fig. 13.**).

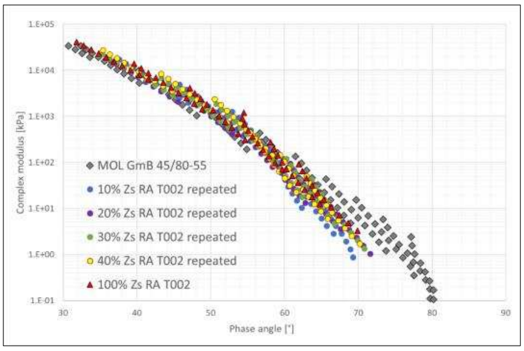

Figure 13. *Black diagrams of Zs RA T002 + GmB 45/80-55 blends – repeated analysis*

It has been observed that the results of the original and the repeated analyses present equivalent tendencies, consequently, it can be stated, that the behaviour of the GmB really differs from the behaviour of PmBs.

6. K RA + OMV 45/80 RC blends

In this series of analysis, an RA bitumen originated from Körmend has been used. The viscosity values showed that in the short in-service life the normal paving grade bitumen has not been aged or degraded to a large extent. The base bitumen used for preparing blends has been an OMV 45/80 RC bitumen. According to the manufacturer, this PmB bitumen type has been particularly developed for recycling with a high RA content, when the „thinning" effect of the RA bitumen has been considered intentionally in the production process of this base bitumen.

There have been small differences between the measured and the calculated viscosities according to **Table 7**. The changes in Black diagrams at 10-20-30-40% RA bitumen contents are presented in **Fig.14**. As it has been previously observed, in case of different blends of PmB and RA, though the RA bitumen changes the characteristics of the PmB, at the 10% to 20% RA proportion in the range of high temperature and low frequency, phase angles still have remained typically low. **Fig. 15**. shows that there has been no significant difference between the characteristics of the 45/80 RC bitumen and the PmB 25/55-65 bitumen.

Table 7. *Summary of tested and calculated viscosities for K RA + OMV 45/80 RC bitumen blends*

RA % (in blend)	***Tested viscosity (Pa.s)***	***Calculated viscosity (Pa.s)***	***Difference (%)***
10	1 811	1 790	1
20	1 307	1 420	-8
30	1 292	1 132	14
40	1 076	907	19
100% K RA	339		
100% OMV 45/80 RC	2 269		

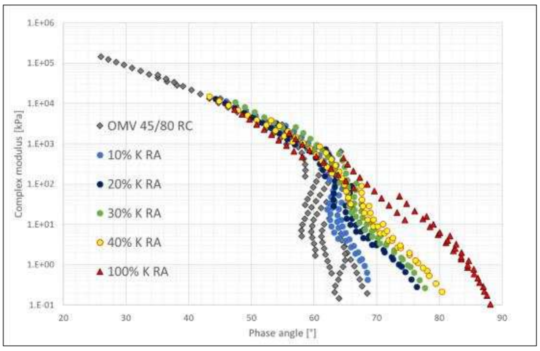

Figure 14. *Black diagrams of K RA + OMV 45/80*

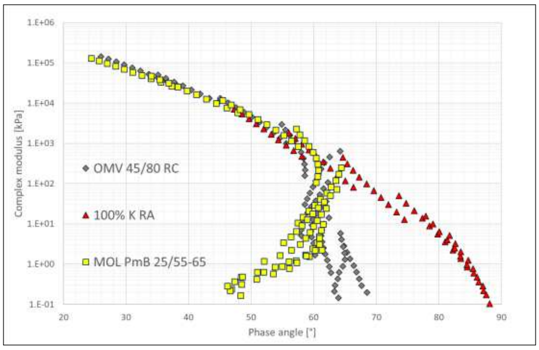

Figure 15. *Black diagrams of the K RA, the OMV 45/80 RC and the MOL PmB 25/55-65 bitumens*

7. OMV B35/50 + MOL GmB 45/80-55 blends

As it has been presented beforehand, the Körmend originated RA bitumen has not been aged or degraded to a large extent, therefore it can be assumed, that its behaviour is similar to a harder grade road paving bitumen. It has also been presented that the behaviour of the MOL GmB 45/80-55 is not similar to the SBS modified PmBs, even though they are characterised similarly by penetration and softening point in the EN product standard. In the next series of analysis, an effort has been made to map the effect of a harder grade road paving bitumen (or a less aged non-PmB RA bitumen) on the GmB characteristics. Therefore, blends of the OMV B 35/50 and the MOL GmB 45/80-55 bitumens have been prepared with 10-20-30-40% proportions. Results of this analysis are summarised in **Table 8.** and on **Fig. 16.**

The characteristics of the blend of the GmB 45/80-55 bitumen with higher B 35/50 content increasingly have approached the characteristics of the plain B 35/50. As it has been already presented it was found again in this series that the measured and the calculated viscosity values are fairly different for the GmB and its blends.

Table 8. *Summary of tested and calculated viscosities for OMV B 35/50 + MOL GmB 45/80-55 bitumen blends*

B 35/50 % (in blend)	***Tested viscosity (Pa.s)***	***Calculated viscosity (Pa.s)***	***Difference (%)***
10	2 186	1 386	58
20	1 981	1 209	64
30	1 681	1 056	59
40	1 592	925	72
OMV B 35/50	517		
MOL GmB 45/80-55	1 591		

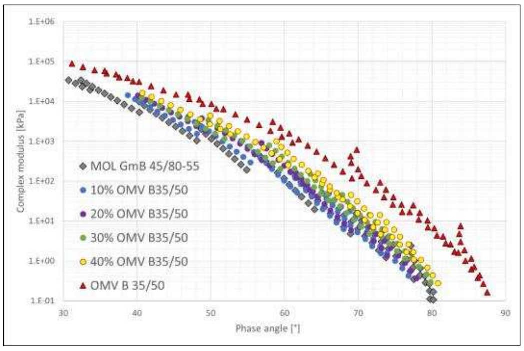

Figure 16. *Black diagrams of OMV B 35/50 + MOL GmB 45/80-55 blends*

8. Zs RA T002 + OMV 45/80RC blends

Finally, the OMV 45/80 RC base bitumen has been blended with 10-20-30-40% proportions of RA, using the harder RA binder extracted from the Zsámbék sample. According to **Table 9**, as already experienced in case of the harder RA, there has been a large difference between measured and calculated viscosities. **Fig. 17.** shows the Black diagrams, where results are in accordance with previous experiences, indicating that the 10% and 20% RA contents have not significantly changed the characteristics of the PmB. There has also been a possibility to plot together the Black diagrams of the Zsámbék and the Körmend originated RA bitumens as well as of the MOL PmB 25/55-65 bitumen (**Fig. 18.**), showing a significant difference between two types of RA bitumens originated from different sources.

Table 9. *Summary of tested and calculated viscosities for Zs RA T002 + OMV 45/80 RC bitumen blends*

RA % (in blend)	***Tested viscosity (Pa.s)***	***Calculated viscosity (Pa.s)***	***Difference (%)***
10	1 862	2 818	-34
20	2 397	3 515	-32
30	3 138	4 404	-29
40	4 496	5 545	-19
100% Zs RA T002	16 748		
100% OMV 45/80 RC	2 269		

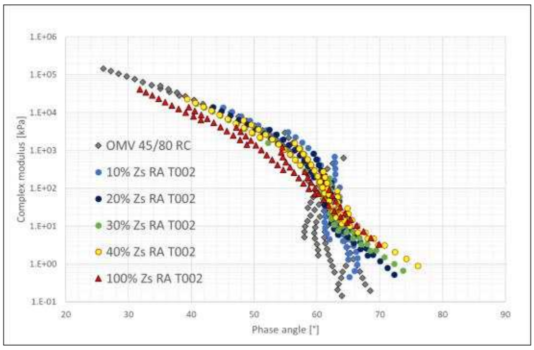

Figure 17. *Black diagrams of Zs RA T002 + OMV 45/80 RC blends*

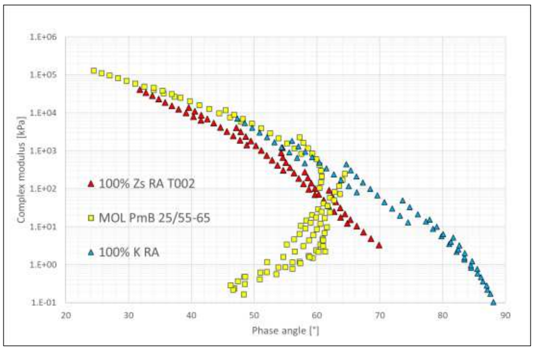

Figure 18. *Black diagrams of Zs RA T002, the K RA and the MOL PmB 25/55-65 bitumens*

V. Conclusions

Designing and manufacturing hot mix asphalt (HMA) with high recycled asphalt (RA) content have economic and environmental benefits, due to the reduction of primary raw materials, such as crushed stone, bitumen and additives, resulting in the reduction of the overall carbon footprint of the asphalt industry. Incorporating high proportion RA into the manufacturing of new HMA is still at a very low level in Hungary, despite the obvious economic advantages. This paper provides learnings and details with regard to the design and management of the binder blend in the HMA containing high proportions of RA.

Studies of bituminous materials of aged pavement layers found on the Hungarian road network is difficult by applying traditional and mainly empirical test methods, because their bitumen must be extracted in laboratories using a solvent in large quantities when preparing for these tests. Also, the traditional tests are not adequate for describing the total behaviour of bituminous binder blends. Instead, an analysis method has been found and presented in this paper, which makes possible the preparation and testing of a smaller amount of bitumen specimens in the laboratory, characterising base binders, binders extracted from the RA or their blends. There are emerging technologies available in civil engineering, such as digital image correlation method (DICM) to predict behaviours in structures [25]; similarly, the dynamic shear rheometer (DSR) device and the data derived from the DSR test is considered emerging technology and it was found suitable for this purpose.

Samples from different recycled asphalt (RA) sources have been collected and their bitumen has been extracted. Their viscosity has been analysed by a procedural order established by the authors. Based on the test results, the viscosities of blends of different RA content (characteristically 10-20-30-40%) have been calculated as well. Similar blends have been prepared in the laboratory and their viscosity has been measured. Based on the resulting data, it is possible estimating the performance of the binder blend (that is the base binder and the binder extracted from the RA), and consequently the performance of the asphalt mix. This was based on the characteristics of the bitumen extracted from the RA and the base bitumen, and the methodology has been validated.

The results of the analysis of the bituminous binder blends have proved, that in all cases of paving grade bitumen (B), polymer modified bitumen (PmB) and rubber modified bitumen (GmB), the utilisation of a higher proportion of RA content is possible without compromising on the overall characteristics of the virgin binder. In case of the paving grade bitumen, the maximum proportion of RA is determined by the softer bitumen applied. Based on the data presented in this paper, a properly chosen paving grade bitumen makes it possible to utilise up to 40% RA content. Based on large scale asphalt production the methodology of utilising softer bitumen grade has been validated up to 50% RA [26].

For the polymer modified bitumen, the limit of the RA content is 20%, but substituting an RC type bitumen, the RA content may be increased to 30%. For the rubber modified bitumen, the various proportions of RA contents showed no or negligible changes in characteristics of the bitumen. The RA content can reach 30% for this binder type, even without changing the base rubber modified bitumen.

Such rheological characterisation of various bituminous binders, including base binders, binders extracted from the RA and their blends has not been provided for Hungarian conditions before. Based on the DSR characterisation it was possible to evaluate the complex behaviour of the various binder types – B, PmB and GmB. A reliable methodology was also developed for laboratory prepared binder blends and the complex rheological characterisation of these binder blends provided a tool for establishing the risk profile of binder blend performance when incorporating various percentages of recycled binder extracted from recycled asphalt pavement.

The need for future research was identified to ensure reliable use of more than 30% RA in mixes containing PmB; for such application a highly modified PmB binder would be required to compensate for the polymer content in the binder blend containing RA bitumen. Also, further work needs to be completed on the effect of rejuvenator agents when added to mixes containing paving grade bitumen.

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Author Contributions

Cs. Toth: Conceptualization, laboratory testing, review.

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Disclosure Statement

The authors have no known conflict of interest to declare.

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The relationship between compressive strength and sonic velocity depending on moisture content in case of historical masonry

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Abstract: Historical masonry structures made from locally available materials such as stone, brick, and mud are an integral part of our cultural identity. Moisture content is a critical environmental factor that can significantly impact the durability and strength of these structures. Moisture ingress in masonry can cause detrimental effects such as decreased strength, increased porosity, and reduced bond strength between the mortar and masonry units. Understanding this relationship is crucial for developing effective conservation strategies and maintenance decisions that can help protect these structures from moisture-related damage. This paper explores the impact of moisture content on the compressive strength of historical masonry structures and highlights the factors that can affect this relationship.

Keywords: historical masonry structures; moisture content; sonic testing; compressive strength

I. INTRODUCTION

1. Water absorption

Historical masonry structures are an essential part of our built heritage and cultural identity. These structures are often constructed using locally available materials such as stone, brick, and mud, which have been exposed to environmental factors for many years. Moisture content is one of the critical environmental factors that can significantly impact the durability and strength of these structures. The effect of moisture content on the compressive strength of historical masonry structures has been the subject of extensive research. Moisture ingress in masonry can occur due to various factors such as capillary absorption, rising damp, condensation, and water penetration through cracks and joints. Moisture content can cause several detrimental effects on the compressive strength of masonry, such as decreased strength, increased porosity, and reduced bond strength between the mortar and masonry units.

Understanding the impact of moisture content on the compressive strength of historical masonry structures is crucial for ensuring their preservation and longevity. It can inform the development of effective conservation strategies and maintenance regimes that can help protect these structures from moisture-related damage. This paper explores the relationship between moisture content and compressive strength in historical masonry structures and highlights some of the factors that can affect this relationship.

The water absorption of masonry structures refers to the amount of water that a masonry unit or mortar can absorb when exposed to moisture for a specified period. This property is influenced by various factors, such as the type and quality of masonry units and mortar, the presence of surface coatings or treatments, and the environmental conditions. The water absorption of historical masonry structures can be measured using various techniques, such as gravimetric analysis, electrical resistance, or ultrasound testing. These methods involve exposing the masonry unit or mortar to water for a specified period and then measuring the amount of water absorbed.

The water absorption of historical masonry structures can have significant implications for their durability and strength. It can also affect the bond strength between the mortar and masonry units and the overall structural integrity of the masonry structure. Therefore, it is essential to consider the water absorption of historical masonry structures when assessing their condition and developing conservation strategies.

2. Compressive strength

Determining the compressive strength of historical masonry structures is a crucial step in assessing their condition and determining their structural integrity. The compressive strength of masonry structures refers to the maximum amount of compressive stress that the structure can withstand without failure. The compressive strength is influenced by various factors, such as the type and quality of masonry units, the mortar type and quality, and the construction techniques used.

The compressive strength of historical masonry structures can be determined using destructive and non-destructive testing methods. Destructive testing involves taking samples from the masonry structure and subjecting them to compressive loads until they fail. The compressive strength is then calculated based on the maximum load that the samples can withstand before failure. However, destructive testing is not always feasible or desirable for historical masonry structures. Non-destructive testing methods, such as rebound hammer tests and ultrasonic pulse velocity tests, are commonly used to determine the compressive strength of historical masonry structures [1]. Ultrasonic pulse velocity tests involve transmitting ultrasonic waves through the masonry structure and measuring their velocity. The velocity is then used to estimate the compressive strength of the masonry structure.

It is important to note that the compressive strength of historical masonry structures can vary significantly within the structure due to variations in the quality and composition of the masonry units and mortar, and the construction techniques used. Therefore, it is essential to take multiple samples and measurements from different locations within the structure to obtain an accurate assessment of the compressive strength [2].

The compressive strength of mortar is established by various standards, such as ASTM (American Society for Testing and Materials) and EN (European Norm) standards. These standards provide guidelines for testing procedures, sample preparation, and calculation of compressive strength. For instance, ASTM C109/C109M-20a [3] provides a standard test method for measuring the compressive strength of hydraulic cement mortars using 2-inch cube specimens. The test involves preparing the mortar specimens with a specific ratio of cement to sand, curing them under specified conditions, and subjecting them to compressive loads until they fail. The compressive strength is then calculated based on the maximum load that the specimens can withstand before failure. Similarly, EN 1015-11:1999 [4] provides a standard test method for determining the compressive strength of cement mortar using prisms with a cross-section of 40x40 mm. The test involves preparing the mortar specimens with a specific ratio of cement to sand, curing them under specified conditions, and subjecting them to compressive loads until they fail. The compressive strength is then calculated based on the maximum load that the specimens can withstand before failure.

It is important to note that the compressive strength of historical mortars may differ from that of modern mortars due to differences in the materials and manufacturing processes used. Therefore, the standards provide guidance for testing historical mortars as well, including recommendations for adjusting testing procedures and interpreting results.

3. Sonic testing

Sonic testing is a non-destructive testing method that can be used to determine the compressive strength of mortar. This method involves transmitting sound waves through the mortar and measuring their velocity. The velocity of the sound waves is related to the stiffness of the material, which in turn is related to the compressive strength of the mortar. The sonic testing involves transmitting sonic waves through the mortar and measuring the time it takes for the waves to travel between two sensors placed on the surface of the mortar. The velocity of the waves can then be calculated based on the distance between the sensors and the time it takes for the waves to travel between them. The velocity is then used to estimate the compressive strength of the mortar. In sonic testing, the velocity of sound waves is related to the stiffness of the material, which is in turn related to the compressive strength of the material. The relationship between velocity and stiffness based on [5] is described by the equation (01):

$$\mathrm{E} = 2\rho V_s^2(1+\sigma) \qquad (01)$$

where E is the modulus of elasticity, ρ is the density of the material, V_s is the velocity of the sound waves, σ is the Poisson's ratio of the material. This equation shows that as the elasticity of the material increases with the second power of the velocity of the sound.

If the velocity of the waves is known, the compressive strength of the material can be estimated using empirical relationships between compressive strength and velocity that have been established for the material being tested. These relationships are typically established by testing samples of the material in a laboratory using destructive testing methods, such as compression testing, some relevant paper is listed in table 1.

Table 1. *Relevant studies related to Sonic testing*

Reference	***Material***	***Subject***
Luchin et al [6]	Granite wall	Masonry wall characterization
Parent et al [7]	Limestone	Compressive strength by sonic velocity
Butel et al [8]	Stone	Compressive strength by sonic velocity
Elizabeth et al [9]	Masonry	Compressive strength by sonic velocity
Valente et al [10]	Masonry	Detecting voids and cracks

Sonic tomography is a non-destructive testing technique used to assess the internal structure and properties of materials, including masonry structures. The technique is based on the principles of sonic testing, but involves the use of multiple transducers and data processing to generate a 2D or 3D image of the material being tested. The resulting image provides information about the internal structure and properties of the material, such as the location and extent of cracks or voids, and variations in material properties such as stiffness or density. This information can be used to assess the integrity of the material, identify areas of potential weakness, and inform decisions about repair or conservation strategies.

The advantage of sonic testing is that it is a non-destructive method, which means that it does not damage the mortar. It can also be used for the in-situ testing of the mortar, without the need for removing samples from the masonry structure. This is particularly useful for historical masonry structures where removing samples may not be feasible or desirable. However, it is important to note that the accuracy of sonic testing can be affected by various factors, such as the composition and quality of the mortar, the presence of defects or damage, and the environmental conditions. Therefore, it is essential to ensure that the testing conditions are standardized and that the results are interpreted in the context of the specific conditions of the mortar being tested.

II. EXPERIMENTAL PROGRAMME

1. Testing specimens

The aim of this paper was to establish relationship between the moisture content of historical masonry structural elements and their compressive strength. For this purpose, a test programme was carried out taking into account the following aspects:

- testing historical solid clay brick specimens
- usage and testing of lime binder-based mortars
- creating and testing historically accurate solid masonry specimens made with lime mortars mentioned above
- testing the compressive strength of the brick, mortar and masonry specimens with 2 different moisture content (air dry and quasi wet)
- testing the effect of the moisture content on the velocity of sonic waves

The brick specimens were collected from a demolished house built in the 19th century. The size and weight of the brick specimens were measured before the testing. The average size of the bricks was 14,5x30x6,5 cm with relative high error (some brick had 1-2 cm difference from the standard size). For the testing procedure damaged and not whole bricks were filtered and ignored.

The lime mortar specimens were created in the laboratory of the Department of Civil Engineering UP with 40x40x40 mm size. Based on the review book of Attila Déry (Öt könyv a régi építészetről – 5 books about the old architecture) [11] historically accurate Hungarian mortar mixtures were obtained. In table 2 the mortar types and mixtures are listed used in the experimental programme.

Table 2. *The mixture of the tested mortars*

Mortar type	***Binder***	***Sand***	***Water***
FH	1	2	1
AH	1	2	1.1
BH	1	4	1

Three different types of mortars were tested, FH mortar made by quartz sand, AH made by sand with high clay content and finally BH made by mine sand.

Solid clay brick masonry specimens were created with mortars mentioned above and 2 different sample heights in order to find a relationship between sonic wave velocity, moisture content and the number of the mortar joints. For this purpose, 2 different heights of specimens were applied (2 bricks and 3 bricks height).

Sonic testing was carried out before and after soaking the specimens. All the specimens were soaked in water for at least 3 days in order to reach a quasi-wet condition. Before soaking every specimen were weighed to calculate the water absorption. After finishing the Sonic tests, the compressive tests were carried out on each specimen.

2. Water absorption

The water absorption of clay bricks is generally expressed as a percentage of the dry weight of the brick. The American Society for Testing and Materials (ASTM) standard C67/C67M-21 [12] provides a laboratory test method for determining the water absorption of clay bricks. This test involves soaking the brick in water for a specified period and then measuring the weight of the brick after the soaking period to determine the amount of water absorbed. The water absorption of clay bricks can also be measured using non-destructive techniques, such as ultrasound or electrical resistance.

The water absorption of lime mortars is generally expressed as a percentage of the dry weight of the mortar. The water absorption of lime mortars can be determined using various laboratory test methods, such as the ASTM C1585/C1585M-13 [13] test method or the EN 1015-18:2002 [14] test method. These test methods involve saturating the mortar samples with water for a specified period and then measuring their increased weight to determine the amount of water absorbed.

The measured and calculated results of the water absorption tests are discussed in this subchapter. The water absorption value can be derived by the following equation (02):

$$w = \frac{m_{wet} - m_{dry}}{m_{dry}} * 100\% \qquad (02)$$

where w is the water absorption value, m_{wet} is the mass of the specimen after soaking and m_{dry} is the mass of the specimen before soaking.

The tested specimens were soaked for at least 3 days in order to reach the quasi-wet condition. During the soaking great attention was taken for the water amount and level in the wetting boxes, the level of water was above the highest specimen with at least 2-3 cm.

3. Compressive strength

The compressive strength test was performed for each specimen before and after soaking. The test was carried out by Sercomp 7 multi-functional testing machine. The compressive strength CS of the specimens were calculated by the equation (03):

$$CS = \frac{F}{A} \qquad (03)$$

where F is maximum acting load before failure and A is the cross-sectional area of the loaded surface.

4. Sonic testing

The Sonic testing was performed by the ArborSonic testing tool. ArborSonic is sonic tomograph where at most 20 transducers can be installed, the transducers generate waves with 600 Hz frequency. The transducers are nail-like elements, which can be fixed in a hole pre-drilled in the tested material. Due to the relatively small specimen sizes only 6 transducers were used. Data was assessed by ArborSonic software what provides an opportunity to save, download the travel times, calculate velocities and plot images about the tested cross section based on the velocities.

III. RESULTS AND DISCUSSION

1. Water absorption

A. Brick Specimens

6 clay brick samples were selected and tested during the programme. 3 of them were tested in air-dry and other 3 in quasi-wet condition. The main results such as the average value, standard deviation and coefficient of variation can be found in table 3.

The average mass of the bricks in air-dry condition was 5.79 kg, while the average mass in quasi-wet condition was 6.26 kg. The mass of the tested bricks was increased by an average of 14%, which is a relative high water absorption rate. Also, it can be noticed that the Coefficient of Variation value has changed significantly after soaking (from 0.029 to 0.117).

Table 3. *Results of the water absorption tests on brick specimens*

Property	***Air-dry***	***Quasi-wet***
Average mass [kg]	5.79	6.26
Standard Deviation [kg]	0.167	0.736
Coefficient of Variation	0.029	0.117

B. Mortar specimens

The measured properties of the assessed mortar specimens are shown in Table 4.

Table 4. *Main properties of the tested mortar specimens before and after soaking (in bracket CoV)*

Mortar type	***Average air-dry mass [g]***	***Average quasi-wet mass [g]***	***Average water absorption [mass%]***
FH	102.2 (0.015)	119.5 (0.048)	15.8 (0.260)
AH	88.1 (0.102)	124.5 (0.018)	34.4 (0.329)
BH	93.5 (0.051)	109.0 (0.026)	14.2 (0.271)

Table 4 also shows the main data of the tested mortar specimens related to water absorption. The results suggest that the AH mortar has the highest water absorption compared to the other two types. The data also show water absorption CoV values are relatively high (especially the AH mortar with 0,329). Overall, the FH and BH mortar properties are very similar.

C. Masonry specimens

Table 5 provides information about the average air-dry weight, average quasi-wet weight, and average water absorption of six different types of masonry specimens. The coefficient of variation (CoV) is also given in brackets.

The data reveals that the average air-dry weight of the specimens ranges from 8.94 kg to 16.34 kg. The FH 2 brick height specimens have the lowest air-dry weight, while the AH 3 brick height specimens have the highest. The average quasi-wet weight of the specimens ranges from 10.58 kg to 19.13 kg. The FH 2 brick height specimens have the lowest quasi-wet weight, while the BH 3 brick height specimens have the highest.

The water absorption percentage of the specimens ranges from 16.88% to 18.55%. The AH 2 brick height specimens have the lowest water absorption rate, while the BH 2 brick height specimens have the highest. Interestingly, the FH 2 brick height and BH 2 brick height specimens have the highest water absorption rates despite having the lowest air-dry and quasi-wet weights.

The coefficient of variation for each property varies from 0.032 to 0.098. The lowest CoV is observed for the BH 2 brick height specimens for water absorption, which indicates that the specimens are relatively consistent in terms of their water absorption rate. The highest CoV is observed for the BH 2 brick height specimens for air-dry weight, indicating that there is a high degree of variability in the air-dry weight of these specimens.

2. Sonic testing

A. Brick specimens

Sonic testing was carried out on each brick specimen before loading. Half of the specimens were tested before and after soaking in order to find the sonic velocity change due to wet condition. The test results are given in table 6.

B. Mortar joints of the masonry specimen

Due to the small size of the mortar specimens the application of Sonic test was not possible. Instead, it was carried out on the mortar joints in the masonry specimens. In table 7 the results of this testing are listed.

Table 6. *Results of the Sonic tests on brick specimens*

Property	***Air-dry***	***Quasi-wet***
Average velocity [m/s]	1563	1675
Standard Deviation [m/s]	164.8	279.1
Coefficient of Variation	0.126	0.166

Table 5. *Main properties of the tested masonry specimens (in bracket CoV)*

Masonry type	***Average air-dry mass [kg]***	***Average quasi-wet mass [kg]***	***Average water absorption [mass%]***
2 brick heigh with FH mortar	9.85 (0.098)	11.64 (0.084)	18.30 (0.098)
3 brick heigh with FH mortar	14.66 (0.053)	17.41 (0.039)	18.55 (0.081)
2 brick heigh with AH mortar	10.22 (0.087)	11.94 (0.083)	16.88 (0.066)
3 brick heigh with AH mortar	16.18 (0.056))	19.16 (0.057)	18.44 (0.056)
2 brick heigh with BH mortar	8.94 (0.211)	10.58 (0.208)	18.43 (0.032)
3 brick heigh with BH mortar	16.34 (0.074)	19.13 (0.070)	17.08 (0.070)

Table 7. *Results of Sonic testing on the mortar joints of the masonry specimens (in bracket CoV)*

Mortar type	***Average air-dry velocity [m/s]***	***Average quasi-wet velocity [m/s]***	***Average difference between air-dry and quasi-wet [%]***
FH	617.2 (0.292)	683.5 (0.283)	12.2
AH	785.0 (0.347)	706.0 (0.325)	-10.6
BH	611.6 (0.307)	763.8 (0.292)	25.6

The result of the table shows that the relationship between velocity and moisture content is highly variable. Usually, the average velocities increase with the increasing moisture content except for the AH mortar. The increase of velocity is in range 12 to 25%. Also, the results show that the CoV values are very high for both air-dry and quasi-wet conditions, indicating that the applicability of Sonic testing only for mortar assessment is limited.

C. Masonry specimens

On the masonry specimens another Sonic testing was carried out. The sensors were inserted into pre-drilled holes in the brick in order to find the effect of mortar joint on the Sonic velocity. The results are shown in table 8.

It is clearly seen that the Sonic wave velocity was increased with the moisture content. The difference is very significant, nearly 25% in case of FH mortar, but more than 40% for the other 2 mortar types. Also noticeable that the CoV values are relative high for both air-dry and quasi-wet conditions (but in case of wet medium it is smaller than in air-dry condition).

3. Compressive strength

A. Brick specimens

Before starting the test, each brick was covered with a thin layer of cement mortar in order to create parallel planes and reduce the effect of inaccurate load distribution caused by rough surface. Table 9 provides information about the results of the tested bricks.

The results indicate that the strength of the bricks decreases when they are exposed to moisture with an average of 16%. The coefficient of variation for both air-dry and quasi-wet conditions is relatively low, suggesting that the results are reliable and consistent.

B. Mortar specimens

Table 9. *Results of the compressive tests on brick specimens*

Property	***Air-dry***	***Quasi-wet***
Average strength [MPa]	17.4	14.7
Standard Deviation [MPa]	3.66	3.00
Coefficient of Variation	0.210	0.205

4 mortar specimens were created from each type of mixture for air-dry and quasi-wet condition, altogether 24 pieces. Results are listed in table 10.

Table 10 shows that there were significant differences between the tested mortars regarding the compressive strength of them. The strongest mortar type in air-dry condition was AH with 2.16 MPa, on the other hand the CoV value was the highest as well. The FH mortar had an acceptable strength value with relatively small CoV value. The BH mortar was the weakest with 0.65 MPa, which is considered as extra weak mortar. From the results it is clearly seen that there is an obvious relationship between the compressive strength and moisture content. The strength was reduced by at least 15 % (in case of BH mortar), but for the AH mortar the loss was more than 40%.

Table 10. *Compressive strength of mortar specimens (in bracket CoV)*

Mortar type	***Average air-dry strength [MPa]***	***Average quasi-wet strength [MPa]***
FH	1.42 (0.090)	0.82 (0.058)
AH	2.16 (0.178)	1.74 (0.122)
BH	0.65 (0.121)	0.55 (0.125)

Table 8. *Results of Sonic testing on the masonry specimens (in bracket CoV)*

Masonry type	***Average air-dry velocity [m/s]***	***Average quasi-wet velocity [m/s]***	***Average difference between air-dry and quasi-wet [%]***
FH	676.5 (0.215)	844.9 (0.166)	24.9
AH	650.9 (0.174)	915.8 (0.172)	40.7
BH	633.7 (0.211)	926.4 (0.218)	46.2

C. Masonry specimens

Masonry specimens were created by the collected historical bricks and mortars prepared in laboratory. The aim of this test was to find a relationship between the Sonic velocity and compressive strength of masonry specimen. The compressive strength of the masonry specimens usually reduces by the increased moisture content. Table 11 shows the results.

The results show that the effect of mortar strength to the masonry strength is not significant in case of low strength mortars. The compressive strength of air-dry masonry specimens made by AH and FH mortars are very similar, and the BH mortar made masonry strength is quite close to the AH and FH ones. After soaking the compressive strengths were reduced by range of 11-16%. Noticeable that the CoV value was increased up to 0.334 with increasing the moisture content (change was very significant in case of BH made specimens).

Table 11. *Compressive strength of masonry specimens (in bracket CoV)*

Masonry type	***Average air-dry strength [MPa]***	***Average quasi-wet strength [MPa]***
With FH mortar	5.35 (0.270)	4.73 (0.334)
With AH mortar	5.28 (0.258)	4.57 (0.301)
With BH mortar	4.91 (0.153)	4.22 (0.323)

IV. Conclusions

The aim of the paper was to find a relationship between the compressive strength and Sonic velocity depending on moisture in case of historical masonry compression structural elements. A large number of specimens were created, tested and analysed. Brick specimens were collected from a demolished house from the 19th century, historically accurate mortar specimens were mixed and finally masonry specimens were created.

In the testing programme 3 kind of tests were carried out such as water absorption, sonic testing to measure the velocity and prism test. Water absorption test was done by soaking the specimens at least 3 day long. Sonic test was done by specific tool called ArborSonic. The compressive strength of specimens was measured by Sercomp 7 multi-functional testing machine.

From the results it can be concluded that the water absorption value of the tested brick, mortar and masonry specimens was significantly high (in some specimen it reached 20 mass%), which demonstrates the remarkable compressive strength loss of all the specimens. Due to this fact the loss of compressive strength was remarkable for all specimens. On the other hand, higher Sonic velocities were measured on the specimens after soaking.

Based on the testing programme, if was found that Sonic tests can be a suitable tool to estimate the compressive strength of historical masonry, but a strong dependence was found between the sonic velocity and moisture content. Furthermore, the effect of moisture on sonic velocity was found different than that observed in standard destructive tests. Overall, the compressive strength cannot be determined accurately by the Sonic velocity without knowing the moisture content of the assessed masonry structure.

Author Contributions

A. Dormany: Testing, Data analysis and writing.

Z. Orban: Supervision, Review and editing.

Disclosure Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Pandemic COVID-19: challenge strategic decisions on building in Egypt

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Abstract: COVID-19 threatens the livelihood and lives of people all over the world. Presently, the disease presents a major health concern in Egypt and all over the world. Evaluating the built and physical environment is one of the solutions to reduce epidemic impact before developing its medications (as "prevention"). Epidemics have altered the usage of our built environment because of the infection fear. As a result, urbanism and architecture will never be the same after the COVID-19 epidemic. However, the current global epidemic poses significant challenges in the built environment at all levels, developing an antivirus-enabled paradigm to stop the spreading of virus or decrease the potential risks will take time. Many unanswered questions require further multidisciplinary studies. This investigation provides an overview for impact of the current COVID-19 Pandemic on the field of residential architecture and how it might change the architecture of built environment.

Keywords: COVID-19; built environment; residential architecture; Egypt; strategic decision

I. INTRODUCTION

Architects have long been preoccupied with the concept of "existence minimum" or "the minimum dwelling," as the critic Karel Teige titled his 1932 book. In the pandemic time, we have reached a new stage of disease and architecture, where scare of contamination becomes again controls our types of spaces that we want to be in. The housing sector's near future will significantly affected by COVID-19 and our long term staying inside housing. Consequently, we must think about space. For architects, it's an inspire-searching exercise, especially if you live in a home that you have prepared for yourself. At the strategic level, the planning and decision includes the leaders of political-administrative sector that provide strategic decisions in the circumstances and carry administrative and political responsibility. They provide public accounts of events, implementation, and support necessary coordination, cooperation, and collaboration [1]. During pandemics, decision making, and its implementation is a challenging task for governments, and it becomes more complex when invisible (virus) pandemics are transmitting and spreading rapidly through human contact [2].

COVID-19 influences most directly the physical health and has alarming impacts for social and emotional functioning; the COVID-19 has proven that a catastrophe doesn't fight with a visible enemy. The opponent can simply be invisible with serious consequences [3-4]. Like the spreading of computer virus, the COVID-19 is rapidly spreading and causes significant catastrophe [5]. Applying lessons from the cybersecurity world during the COVID-19 pandemic could be useful to protect and preserve our built environment. In the digital world, incorporating and designing solutions are common practice that can help to reduce the effects of pandemic and overcome virus attacks; a new security layer is added for every new generation, to ensure the ever-mutating computer viruses do not harm the digital infrastructure [6]. Could planners, architects and policymakers exploit this digital world learn from its cybersecurity to provide us by more resistant built environment to the virus? Could we design and build our housing sector to stop the spreading of a virus?

Infectious disease has already altered our places through design, urban planning, and architecture. Previously, several trends in architecture and urbanism that we see today were derived from similar measures taken before to ensure the health, hygiene, and comfort of urban residents [7]. Our built environment has always exhibited the capacity to evolve after the crisis [8-10]. The pandemic situations have proved that moving away from cities is not only necessary, but also mandatory. Those who live in cities far from the mother city and in the villages and are in less danger than others, because they naturally meet the social distancing standards. In the future of density will be a basic question. Pandemic COVID-19 influences to build, design, and inhabit cities may never be the same. Nevertheless, we must remind that things were once normal and could be again, that the rest of the world still exists. We should be able to hibernate.

This study reviews architecture and urban developments from the past centuries. We present the challenges for the energy sector. Then, we analyze the domestic space and interior design in the post-pandemic era. The main objective of this research is to exploit this forced experiment to provide additional layers of security to overcome the future epidemics and present the study's vision about the antivirus-built environment, we take Egypt as an example.

II. Previous dramatic change management:

Georges-Eugène Haussmann started his remaking of Paris in the eighteen-fifties. Demolishing crowded districts of the medieval age, which were believed of as pestilential, in favor of grand city plans and broad avenues with public squares and geometric parks presenting an introduction to the Euclidean modernist developments in the twentieth century. Urbanism focused on undoing this model over the past few decades, cultivating organic density through mixed-use zoning and smaller studio apartments. Currently, because of pandemic, Armborst said, "we're in a situation where density is something to be avoided" [11]. The challenge is reconciling the need for a long-term architectural plan with the unknown of pandemic's ongoing represents the major challenge. Against this background, developing our built environment is essential in the current health crisis to increase the security layers that help to stop the spreading of diseases and infections. Several areas of research are required in this context.

The pandemic's effect on urbanism has observed in small changes that can be applied faster than a new zoning plan or building. Closed streets in Vilnius, Lithuania's capital, were opened to cafés and restaurants so that tables could be arranged at appropriate distances. The fear from infection during pandemics controls the form, just as much as the function [12]. From interiors to city planning, our built environment is shaped by diseases. Previously, people redesigned cities, architecture, interior design, and infrastructure to minimize the risk of infectious diseases. The urban story and architecture include numerous developments through reviewing historical events of the last two centuries like urban renewal, sanitary reform, and building/housing reform.

A. Interior Design

Interior design presents an ideal of domesticity. The Bauhaus architect Hannes Meyer wrote "Each age demands its own form," in his 1926 essay, "The New World." "Ideally and in its elementary design our house is a living machine." Meyer argued in the twentieth century, "architecture has ceased to be an agency continuing the growth of tradition or an embodiment of emotion".

B. Domestic Space

Most people are more intimately aware of the confines of their houses during Quarantine. We know every detail about them, especially the lack of daylight in a single room, their flaws, the need for an extra bathroom and the dirty floor in another. Day-lighting studies in buildings play a significant role in indoor environmental investigation and can be applied already at the early stages of building design [13]. Consequently, we must think about space. For architects, it's an inspiring exercise, especially if you happen to live in a home that you have prepared for yourself.

III. Research areas and Questions Method and Design Problem

When the World Health Organization (WHO) declared the fast-spreading COVID-19 as a pandemic, citizens around the world hastened to stay at home. This global pandemic significantly affected our professional and personal lives and has a direct impact on foundations of architecture theory and practice, and urban planning. **Fig.1** shows the design problem and challenges for the future built environment. The pandemic raised some questions of how architects could present and install antivirus-related ideas or update the existing spaces, as well as at what stage can the pandemic influence our physical and built environment. To extend the scope of research needed from the academic community,

we studied the current situation in Egypt as an example through covering the following questions:
What is the impact of the current pandemic on the field of Residential Architecture?
How will the COVID-19 pandemic change the architecture of the built environment?
What is the effect of COVID-19 Pandemic on the energy and environment sectors?
What are the strategic policy tools that Egyptian government implemented during the pandemic?

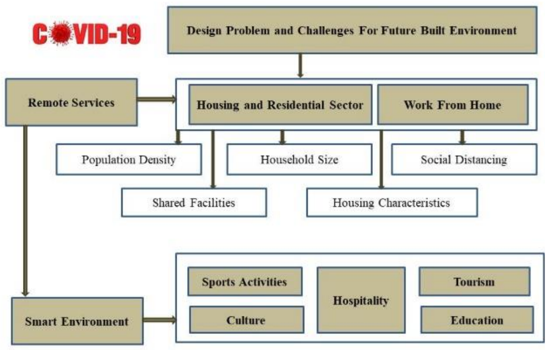

Figure 1. *Design problem and challenges for the future built environment*

The government portals of the Republic of Egypt Ministries, Directorates and Relevant Public Institutions dealing on issues of built environment, health and safety are the key data sources in this research. Other sources such as reports, articles of national, public organizations, national newspapers are also included in this study and lessons learned from previous pandemics. The lockdown of the population and physical distancing are among the most precautionary and immediate measures to be applied in the absence of a medication to the coronavirus. The WHO presented these measures to practice at both individual and institutional levels to become a global mainstream strategy [14-15].

IV. COVID-19 AND THE CHALLENGES FOR ENERGY ACCESS

Energy access represents a critical issue in Egypt. The large portion of energy used to provide cooling, lighting, and different equipment of buildings in hot and arid climate like Egypt [16-19]. Lack of finance, skilled workforce, infrastructure quality, conducive environment of business represents the key challenges. Moreover, the weak health system in Egypt has been exacerbated by low access to reliable and modern electricity resulted in the fast spreading of pandemic in the continent. Also, it is expected that the crisis will bring ample opportunities. COVID-19 causes another negative effect on the renewable energy growth -based businesses like distributors and PV suppliers. The disruption of supply chain of renewable energy technologies considered as the greatest negative effect of COVID-19 is mainly because worldwide transportation being halted and the source of these technologies such as USA, China, and Germany focused their attention to deal with the COVID-19 pandemic [20]. Egypt should exploit the learned lessons of COVID-19 pandemic to reinforce the demand of sustainable energy transitions. The Passive design strategy is considered as one of the most effective approaches to reduce energy consumption and enhance occupant's thermal comfort in buildings [21]. Egypt has to focus on localizing the manufacture of renewable energy technologies after global disruption of supplying renewable energy technologies as this disruption influencing the unsustainable businesses that involved in the energy sector. The Egyptian government has made substantial effort in providing conducive environment of business including implementing strong project with monitoring and evaluation to encourage developing partners to provide more fundings. In case of placing figures and tables use a Text Box. The text box includes the figure or table and its caption. The text box fitting must be square type in the "wrap text" option. Normally the width of figures and tables must not be wider than 7 cm to fit in a column. If it is necessary to use wider tables or figures, it can be used 15.5 cm wide, but in this case, it must be fit to the top or the bottom of the page like **Table 2**.

V. COVID-19 AND THE ENVIRONMENT

The pandemic has a significant effect on the world's environment. During the pandemic oil and other fossil fuel demands has damaged with transportation systems and a halt of industries leading to a rapid change in the environmental system. Studies in the COVID-19 epicentres such as China, the USA and Spain, showed that pollution has decreased up to 30% [22] with Rio de Janeiro, observing an average reduction of (30.3% - 48.5%) in CO levels [23] and Delhi showing an improvement in air quality by 40% to 50% within four days of lockdown [24]. Thus, the world must change the way of doing business prior to the pandemic and this is the greatest opportunity in the word and particularly for the African continent to invest more in reliable and clean energy resources.

VI. THE CURRENT SITUATION OF EGYPT AND NEW ROLES

Egypt has acted quick response and implemented several strategic policy tools such as curfews, quarantines, travel restrictions, or travel bans, closing schools, colleges and universities, as well as 'moral suasion' to promote 'stay at home', 'social distancing' and personal protection etc. Considering both regional and local scale of environmental, the

Republic of Egypt Ministries, Directorates and Relevant Public Institutions dealing with the issues of urban built environment have taken a number of consequential strategic decisions on built environment. The current situation of COVID-19 is in line with the strategy of the Egyptian government to reduce the population congestion of cities by moving to new urban communities and taking strict measures such as permanently halting construction and Building licenses and demolishing what was built in violation from the date of April 2020 until the current situation is studied as shown in **Fig.2**.

Figure 2. *Examples of Demolishing Buildings [25]*

The state paid special attention to the establishment of new urban settlements. With the aim of reducing congestion in old cities, and countering the steady population increase, many housing, infrastructure and services projects are being implemented in the expansion areas of the existing urban agglomeration. Egypt achieved a rapid fulfilment in terms of improving the level of infrastructure through mega national projects in developing road projects. Where nearly 400 projects have been implemented, within the framework of the state's interest in the road and bridge sector to accommodate the increasing volume of transport while achieving traffic fluidity (**Fig. 3**).

More than 20 new urban cities have been implemented in various parts of the republic, including [26]: "The New Administrative Capital - New Alamein - New Mansoura - East Port Said - Nasser in West Assiut - West Qena - New Ismailia - New Rafah - Al Jalalah City - New Farafra - New Obour - New Toshka - East Owainat - New Sphinx - New Bir al-Abd - New Aswan. It has been planned that the new urban cities, upon completion of all phases, will accommodate about 15 million people, and provide about 6 million permanent jobs. Out of the state's interest in providing adequate housing for citizens of all classes, a number of projects have been implemented that reached nearly 1,000 projects with a total cost of nearly 100 billion pounds, which comes within the framework of the state's keenness to achieve social justice for all segments of society, and implementing many housing projects that suit limited and middle-income groups by constructing 300,000 social housing units and 25,000 medium housing units. In addition to the implementation of 15,000 youth housing units and the implementation of 75,000 housing units to house the residents of the units in dangerous, life-threatening areas, in order to eliminate slums, and work to remove sources of risk from units that are under high pressure lines or within the scope of industrial pollution [26].

Figure 3. Examples of new urban cities in Egypt [26]

These included the construction and duplication of new roads with a total length of 4,700 km, the development and upgrading of the efficiency of 2530 km of roads, the implementation of 6 axes on the Nile, in addition to the implementation of 240 industrial works, "car and pedestrian bridges - car and pedestrian tunnels. In the railway facility, 500 km of railways have been renovated, 100 stations developed and maintained, in addition to the comprehensive development of about 400 slides, the addition of 240 new air-conditioned vehicles. In the metro facility, 24 air-conditioned trains were supplied for the first / second line [26].

VII. PROPOSED APPROACHES OF POST PANDEMIC ARCHITECTURE AND URBANISM

COVID-19 will change architecture, the way we design, build, and inhabit cities may never be the same. **Fig. 4** presents the proposed approaches of post pandemic architecture and urbanism. For parks and public spaces, several health, physical and environmental benefits, are offered like providing numerous opportunities for physical activity, social integration, and mental rejuvenation. The Ministry of Internal Affairs has banned people aged above 65 years from leaving their homes and open spaces including gardens and parks that cause chronic disease. The promenade and recreation area accommodate one person per 4 square meters and number of people intake inside the garden/park should be arranged accordingly (Ministry of Health). Green environment and safe water are essential to fight against viruses thus, green interiors inside buildings and green buildings are more specifically adaptation-based strategies on climate change that will be fruitful in several uncertainties [27].

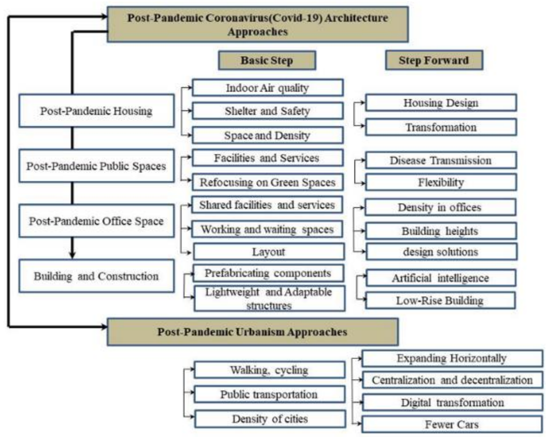

Figure 4. Proposed approaches of architectural and urbanism post pandemic.

To ensure healthy neighborhood or community, comprehensive communities planning will be required to prepare public health in designs, zoning, and other necessary enhancements. In this prospect, smart technologies in urban planning and management, an integration of urban design, and approaches of disaster response are also required. The principle of designing built environment is to create safe public spaces to bring people together, increase social interaction, and deal with social disparities in urban areas. Although densification is essential to accommodate population growth in the cities, de-densify inside buildings by physical spacing with adequate and proper provisions of health rules can be represented as a solution for future building design. Natural driven ventilation is a widely applied technique in hot and arid climates as it can lead to significant energy saving as well [28].

CONCLUSION

The COVID-19 pandemic has presented the limitations of how we manage our built environment in relation to how we should design, and operate our built environment; however, it has provided us an opportunity to learn. Also, if we harness the security layers to a healing approach that could be implemented in the post-pandemic era, it could help to provide us by more resistant and a sustainable built environment. It can be concluded that the operational decision and robust strategies can reduce spreading virus or mitigate its negative effects. Choosing the optimal antivirus strategy relies on many factors such as the capabilities and abilities of each community and environment. This study provides the measures and decisions that have been taken by the Egyptian government till new normal period on the perspective of urban built environment. It is required to draw lessons from new normal and post-pandemic period to combat present and future challenges. Findings indicated that although socioeconomic indicators were the main variables affecting COVID-19 cases, the built environment had an impact on COVID-19 cases in a variety of ways. The density of the built environment was found to be positively related to incidence rates. Overcrowded households increased incidence rates within each community. Thus, the governments and the people should make concerted and coordinated effort in exploiting the presented opportunities to facilitate renewable and clean energy technologies and developing conducive environment of business to achieve the sustainable development goals and facilitate energy access. Overall, the pandemic recovery represents a historic opportunity to tightly ground placemaking in environmental sustainability, human needs, and justice to adopt metrics and indicators that reflect those priorities; to improve the efficiency and fairness of urban governance; and to utilize emerging technology to create healthier, more sustainable, places than ever before.

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AUTHOR CONTRIBUTIONS

S. Elhadad: Conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, visualization.

Z. Orban: Conceptualization, validation, resources, writing—review and editing, supervision, project administration, funding acquisition.

A. Fülöp: Validation, resources, writing—review and editing, supervision, project administration, funding acquisition.

DISCLOSURE STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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