Developing European Defense Strategy for Electromagnetic Resilience Infrastructure Network

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***Abstract*—As part of the Design Process Model that includes systematic methods for the 'Developing European Defence Strategy for Electromagnetic Resilience Infrastructure Network' this paper focuses on the analytical phase. In essence, the paper presents inductive reasoning (develop a theory), while also examining deductive reasoning (proposed solution) to promote the need and resources of the creative phase (development of such a strategy). The paper focuses on Spectrum capabilities in defense and acknowledges that the development of European Defense strategy for Electromagnetic Resilience Infrastructure is necessary. Issues such as interoperability, and ability to keep pace with technological advances by potential adversaries will require Europe to emulate recent developments by DoD to advance the USA superiority in EM warfare. The result of this paper will identify opportunities, risk and challenges within the scope of the European Defence Strategy for Electromagnetic Resilience Infrastructure Network.**

Keywords—Electromagnetic Spectrum; Resilience; Strategy; Infrastructure; Networks; Energy; Standards.

I. INTRODUCTION

In physics, Electromagnetic Radiation (EM radiation or EMR) refers to the waves (or their quanta, photons) of the electromagnetic field, propagating (radiating) through space, carrying electromagnetic radiant energy. It includes radio waves, microwaves, infrared, (visible) light, ultraviolet, X-rays, and gamma rays. In applications across civil, commercial, and government sectors, the characteristics of the waves used often drive the use [1] . Table 1 is an extraction from [2] and cross-referenced by the author to identify the specific use of the spectrum in Space and Defence. It highlights the theme of the paper's magnitude for reflection on Spectrum capabilities in defence.

In February 2021, the Congressional Research Service Report outlined DoD use of the EMS (Electromagnetic Spectrum) based on: (i) Interoperability, (ii) Ability to keep pace with technological advances by potential adversaries, (iii) The private sector's increasing interest in using frequencies traditionally reserved for the military (for example the 5G spectrum), (iv) Spectrum Sharing, (v) The interagency process for spectrum allocation – such as the Federal Communications Commission (FCC) authorisation of the Ligado 5G network, which could affect the global positioning system's radio signals, and (vi) Anticipating future spectrum needs for both commercial and military users. These principles have called the DoD to action and develop a strategy to control and enable these 6 principles in order to advance the USA superiority in EM warfare.

TABLE I. ELECTROMAGNETIC USES AND APPLICATIONS (EXTRACTED FROM [2])

Directed-Energy (DE) Weapons	**Concentrated EM energy** rather than kinetic energy to incapacitate, damage, disable, or destroy enemy equipment, facilities, and/or personnel examples include ground forces in Counter Rocket, Artillery, and Mortar (C-RAM), Counter-Unmanned Aircraft (C-UAS), or Short-Range Air Defense (SHORAD) missions.
Radio frequency waves	Can be used to transmit messages between electronic devices. Low frequency radio waves can travel long distances, and can penetrate seawater, but cannot support high data rates. These waves are useful for communications with submarines. long distance waves can pass through solid objects, like buildings and trees, making them useful for mobile communications.
Microwaves	Microwaves are used in radars—systems that send out pulses of high frequency waves that reflect off an object and back to the source. Microwaves are also used in satellite communications, which experience few obstacles in their transmission path.
Infrared radiation (IR)	Receives and converts light signals to electrical signals that instruct microprocessors to carry out commands, similarly infrared lasers can be used for point-to-point communications over short distances to provide high-speed, reliable connections.

The paper comprises of 7 main sections: i) introduction - observation and addressing the problem; ii) scope & objectives - what is required and measured; iii) project analysis - evaluation 'why it is needed'; iv) methodology - development of EMC standards and specification; v) proposed solution - how it will be achieved; vi) impact, opportunities & risks - the added value gained from such a strategy and risks associated with trying to achieve it; and vii) way ahead - funding. Overall results of the paper present a summary, synthesize, critique, and use of information as "background" for a research proposal.

II. SCOPE AND OBJECTIVES

This section will address the overall scope of the projects contribution and outline the objectives.

A. Scope

This project is a contribution to the development of the European Defence Strategy for Electromagnetic Resilience Infrastructure and raises the profile of its activities in particular by working on the following: i) support the operation of the European Defence Agency (EDA)

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governance structure; ii) conduct national and regional based process for preparing a Research and Innovation investment Roadmap and priorities by involving research and industry stakeholders, and engaging in wide dissemination of the Electromagnetic Resilience Infrastructure results; iii) organise outreach events and engage in structured discussions with the general public, including on the social implications and ethics of Electromagnetic technology development and innovation, particularly with regard to privacy and security, public trust and acceptance; iv) provide research dissemination services to projects; v) identify relevant training, education and infrastructure needs. The results should be compared with best practices of international cooperation partners of similar governance (e.g., USA and Canada), and shared based on mutual exchange.

B. Objectives

1. Investigate and map best practice activities in European and international spheres - where Electromagnetic technologies will play a major role in the near future and where resilience in such fields can enhance existing capabilities, protection and offer a competitive advantage to Europe.
2. Increase the adoption of standards and regulations in Electromagnetic Warfare - either in existing standardisation activities and bodies and where relevant, by contributing to creating and testing new standardisation activities in existing groups and/or creation of new groups.
3. Open Innovation Days – mobilise the whole value chain (research, standardisation and the industry sectors, and defence sectors) at innovation days and advance the discussions at European level to achieve impactful results promoting the European interests in Electromagnetic standardisation.
4. Perform an extensive mapping of current and future resilient requirements for Electronic Warfare education and training; define standards for implementing appropriate educational strategies; host existing and newly developed teaching materials and resources within a European Defence repository.
5. Develop strategies for scaling up training programmes across Europe in the use cases of advanced Electromagnetic Spectrum Management; and establish a network between science, civil society, and industry to exchange ideas, needs, and human resources.
6. Develop the European Defence Strategy for Electromagnetic Resilience Infrastructure Network - involve and be driven by representatives of the relevant actors of the field (e.g., academia, RTOs, and industry, including SMEs, and intermediaries).

III. PROJECT ANALYSIS

The project focuses on the capabilities of electromagnetic waves and how the infrastructure for supporting such emissions is protected such as **Data Centers and 5G Networks**. EM waves in basic principle carry energy, momentum, and angular momentum away from the source particle and radiates without the need for continuing charges. EMR is sometimes referred to as far field because it achieves sufficient distance from such charges whereas near field are close to charges and the current that produces them. In reference to the incredible evolution of communicating systems; “the deployment of Internet and mobile networks, connected objects and sensors, has brought about the emergence of silicon photonics to meet these new major challenges” [3].

In essence, fiber optical communications have revolutionized the telecommunications industry as well as the data networking community. Fiber optic cables have enabled telecommunications links to be made over greater distances, with lower levels of transmission losses and enabled higher data rates. “As a result, fiber optic communication systems are widely employed for applications ranging from major telecommunications backbone infrastructure to Ethernet systems, broadband distribution, and general data networking [4].

Why is this important? The need for high speed, more capacity and longer distances has made Dense Wavelength Division Multiplexing (DWDM - is an optical multiplexing technology used to increase bandwidth over existing fiber networks) the technology of choice for greenfield installations, for upgrading existing networks, and is compulsory for transmission of 100G and above. In fact, the DWDM C-band 1525nm – 1610nm spectrum supports up to 96 wavelengths spaced at the standard ITU grid of 50GHz [5]. At higher data rates, including 400G and 1T, the signals will be transmitted over multiple subcarrier channels [6]. From a 5G commercial aspect, Intel acknowledged the benefits of their 100G silicon photonics transceivers that are optimised to meet the bandwidth requirements of next-generation communications infrastructure while withstanding harsh environmental conditions. Furthermore, their market opportunity projection for its connectivity business, which includes silicon photonics, is to grow from $4 billion today to an estimated $11 billion total addressable market by 2022 [7].

However, Spectrum Sharing is an issue with emerging technologies and policies are demonstrating commercial systems can use the same frequencies without degrading defense capabilities. Such policies, best practices, standards, and regulations must be referenced within the European Defence Agency context. **Integrated quantum, Photonic Devices, 5G security Networks (such as QKD and system lockout chip)** are not only a part of defence resilience strategies, but also of the cities of the future. Data centers bandwidth for communication and the use of silicon such as Insulated-Gate Bipolar Transistor (IGBT) and Metal–Oxide–Semiconductor Field-Effect Transistor (MOSFET) by STMicroelectronics to discharge batteries in electric and hybrid vehicles **indicate the dependency on the Electromagnetic spectrum and thus the need for protection from advanced Electronic Warfare Systems and Electromagnetic Interference in urban areas such as**:

- Electronic Support, Networking & Cyber Enabling – i) networks with Tactical Radios, ii) electronic support (detect, direction finding and geo-location, iii) cyber-enabling platform.
- Counter Unmanned Aerial Systems (CUAS) – i) integrates with radars, sensors, and fire control solutions, ii) stationary and on-the-move capable, iii) configurable for dismounted, mounted, fixed site and airborne platforms.

IV. Methodology

In practice Electromagnetic Compatibility (EMC) is the engineering discipline concerned with the behavior of a system in an Electromagnetic Environment (EM). According to INCOSE [8]: “A system is considered to be electromagnetically compatible when it can operate without malfunction in an EM environment together with other systems or system elements and when it does not add to that environment as to cause malfunction to other systems.” The term electromagnetic interference (EMI) is recognised when a system causes interference, and in EMC the EM environment includes all effects classically attributed to electromagnetics (such as radiation) and electrical effects (conduction).

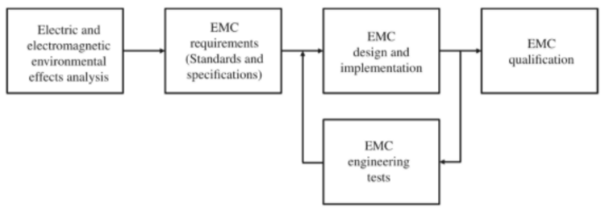

Fig 1. Process for achieving EMC (Arnold de Beer, cited by [8]: INCOSE page 219)

Arnold de Beer developed the Business Process Map (BPM) in Fig 2 which outlines how EMC will be successfully achieved during system development. It has 5 main areas: i) electrical and electromagnetic environmental effects (E4) - this analysis describes all the threats (natural and man-made) that a system may encounter during its life cycle, furthermore MIL-STD-46C [9] is still been used to determine requirements of a system such as installation; ii) EMC requirements (Standards and Specifications) – are used to regulate the EM environment in which a system is operating, however the process acknowledges that existing standards and specifications (whether commercial, military, avionic, automotive, or medical) can be used as EMC requirement based on its class or category according to the outcome of the E4 analysis; iii) EMC Design and Implementation – overall EMC requirements are inputs for the concept and development stages of design that includes both mechanical and electrical/electronic hardware implementations, the use of zoning for system elements with similar emissions or sensitive circuits require a control of interface and the EMI control plan includes EMC requirements, zoning strategy, filtering and shielding, mechanical and electrical design to EMC; iv) EMC Engineering Test – prequalification testing is done on a system element level and even as low as the single circuit board assembly level during the development stage; v) EMC qualification – EMC qualification tests verify the EMC design of a system against its requirements, the first part of such tests is to compile an EMC test plan and map each requirement to a test and a test set up.

Given the severity of EMI and the urban dependency on the Electromagnetic spectrum, the overall methodology is based on re-engineering the process for achieving EMC for urban interoperable design. For instance, challenges exist when testing for EMC qualification as the process must be in operational mode during emission testing to predict malfunctions during susceptibility. Just like EMC standards and specifications when it is impractical to test a large system such as ship, aircraft, or complete industrial plant, the qualification tests are based on the systems elements. In the opinion of this author, there needs to be an updated review EMS based on a similar international structured principle; (i) Interoperability, (ii) Ability to keep pace with technological advances, (iii) The private sector’s increasing interest in using frequencies, (iv) Spectrum Sharing, (v) The Interagency process for spectrum allocation and (vi) Anticipating future spectrum needs for both commercial and military users.

V. Propose Solution

As part of a trains protection system, Delft University have been testing ERTMS/ETCS Hybrid Level 3 and ATO: A simulation-based capacity impact study for the Dutch railway network [10]. A EEIG ERTMS Users Group has been focusing on the implementation of ERTMS/ETCS Level 3, the Hybrid Level 3 concept. “The main characteristic of the concept is that it uses fixed virtual blocks for the separation of trains which are fitted with a Train Integrity Monitoring System (TIMS), while a limited installation of trackside train detection is used for the separation of trains without TIMS, as well as for the handling of degraded situations” [11] (EEIG ERTMS Users Group, page 5).

The common theme here for testing EM designs in reference to requirements is the creation of user’s groups, the analysis of best practices (case studies) and the use of personas. In order to ‘Develop European Defense Strategy for Electromagnetic Resilience Infrastructure Network’, the project must build upon existing networks and create similar Special Interest Groups (SIGs).

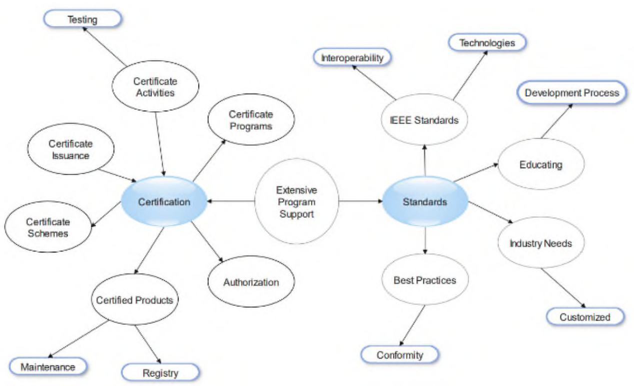

Fig 2. IEEE Standard Association ICAP (Adaption of this Authors, Interpretation)

Figure 2 is a graphical mind map representation of IEEE Conformity Assessment Programs based on the following 10 main points of their ICAP working group Extensive Program Support [12]:

- ICAP is a facilitator and administrator of certification programs.
- Full oversight for testing and certification activities.
- Certificate issuance.
- Development and management of test plans, test suites and certification schemes.
- Maintenance of certified products registry.
- Test laboratory assessment and authorisation.

- Technical and logistical support services to industry groups executing interoperability demonstrations of specific technologies related to IEEE standards.
- Educating IEEE Working Groups on conformity assessment to ensure conformity assessment is injected early in the standards development process.
- The development of customised conformity assessment programs that meet industry needs.
- Defining and designing conformity assessment best practices.

The concept for the Developing European Defence Strategy for Electromagnetic Resilience Infrastructure Network is to build similar SIG groups to the IEEE Standard Association ICAP (IEEE Conformity Assessment Programs) but concentrate on attributes of the DoD 6 pillars.

VI. IMPACT, OPPORTUNITIES & RISKS

The following section will outline the impact of advancements associated to the Electromagnetic Spectrum, the opportunities relating to technologies and infrastructure, and the current known risks and challenges.

A. Impact

Advancements in Electromagnetic Spectrum have revolutionised how we manage, control, use and distribute data that affects our digitally operated devices in order to advance our health and well-being on a daily basis. Optronics (the combination of optical and electronics) such as fiber optic communication and in particular fiber optical receivers have presented opportunities through wide band width devices. With the inclusion of WDM multiplexing technology the capacity to enable bidirectional communication over one strand fiber exists. This is just one example; other added advantages include:

- **Security** – quantum communications such as WDM have been operating through the protection of Quantum Key Distribution (QKD) can offer communication with unconditional security).
- **Speed** – multiplexing enables high speed capacity and high-speed telecommunications.
- **Energy** – i) charge pumps circuits are capable of high efficiencies, sometimes as high as 90–95%, while being electrically simple circuits; ii) MOSFETs and IGBTs are powered by Charge pumps in H bridges in high-side drivers for gate-driving high-side n-channel power [13] ; The Silicon Micro-Ring Resonator (MRR) has gained significant attention for use in an energy-efficient and high-bandwidth photonic system and is ideally suited for both inter- and intra- data center communication [14].
- **Cost** – the use of DWDM (referring to optical signals multiplexed within 1550Nm) leverages cost and capabilities of Erbium Doped Fiber Amplifiers (EDFAs) for wavelengths between C-Band and L-Band, 1525nm – 1565nm and 1570nm – 1610nm.

B. Opportunities

According to RADIO WAVES [15], "Massive Multi-Input Multi-Output (MIMO) antennas provide access to wide frequency bands for very high-speed connections. Their 'agile' technology gives them the ability to direct their beams to countless moving devices thanks to their multifocal technology. As a result, they enhance a better direct signal to the user, by following them as they move. Furthermore, they provide:

- reduced energy consumption.
- the handling of a larger number of users, and increased speeds.
- a significant improvement in signal quality to the user while also reducing superfluous surrounding emissions.

There have been many studies on the role that photonics, particularly microwave photonics, can have in implementing 5G networks. Currently, there are several general disruptive technologies needed for 5G cellular networks, such as small-cell architectures, the utilisation of the millimeter-wave (mmWave) spectrum, and the implementation of MIMO systems at mobile base stations [16]. Other benefits of fiber include the fact that "the mmWave frequency band is a "sweet spot" for Radio Frequency over fiber and mmWave signal with broadband data can be easily transported over large distances with minimal loss [17].

However, interoperability will always be the main issue when exchanging information and standards are the key mechanism to achieving interoperable solutions when developing systems and providing ICD (Interface Control Document). The U.S. Defense Advanced Research Projects Agency (DARPA) has been working on "developing 100 Gb/s RF Backbone (100G) program whose goal is to design, build, and test an airborne Millimeter based RF communications link with fiber-optic equivalent capacity and long reach capable of propagating through clouds and providing high availability." DARPA's focus is to provide a system comprising 100 Gb/s capacity at ranges of 200 km for air-to-air links and 100 km for air-to-ground links when installed in a high-altitude (e.g., 60,000 ft) aerial platform [18]. And these types of systems will adhere to DoD military specifications, therefore if commercial interests are also using frequencies traditionally reserved for the military there needs to be the inducement of technologies such as AI-enabled dynamic spectrum sharing. Such technologies will require best practices regulation and standards to achieve the end game.

C. Risks & Challenges

- The main risks are related to not being able to build upon existing networks and create similar Special Interest Groups (SIGs).
- Another risk is the fact that typical military specifications and commercial specifications would need to be reviewed in order to proceed with a joint strategy for developing European Defense Strategy for Electromagnetic Resilience Infrastructure Network.
- This ambitious project will require collaboration between the Energy Consultation Forum's Working Groups (CF SEDSS), the largest defence energy community in Europe, and support from Institutes such as the European Telecommunication Standard Institute (ETSI) and the *International Telecommunication Union* (ITU). While the CF SEDSS working groups do not implement projects, they can address conceptual design and, through the Forum, EU and Member States funding could be mobilized to produce tangible results.

- Many of the disruptive technologies already exist for implementing the key systems but there is a significant lack of training and open collaboration that can involve all major players that will utilise the EMS with particular reference to resilience system engineering. For instance, the defence and private sectors may not wish to share information.
- To appreciate the challenges, all of the supply chain actors (Large enterprises, Mid-Caps, SMEs) must be included in the discussions at the innovation days.
- There will be challenges and risks associated with tests, particularly the new development of European Defense Electromagnetic Compatibility documents.

VII. Way Ahead

This section will focus on the core theme 'a possible project', case study, and funding mechanisms.

A. *Theme*

A possible project would be to develop a framework for assessing EMS resilience in power plants in the context of hybrid threats that can be offered to Member States, along with a toolkit of best practices, guidelines and technical solutions to ameliorate the risks. The project could have a practical implementation at the level of 1 or 2 power plants volunteered by one of the participating Member States. It can also propose to deliver a network of stakeholders, including developers, beneficiaries, expert groups and research labs, to serve as a resource for supporting future efforts.

B. *Case Study*

According to [19] a case study is a strategy used to research an experimental theory or topic using set procedures. The authors are of the opinion that testing a case study starting at TRL2 (technology concept formulated) and finishing at TRL 4 (technology validated in lab) will add significant value to any potential funding key performance. Figure 3 below shows how pre-existing components (databases, platforms) and concepts of EMC for BIM model structure topology can be configured to developed 'Resilience System for Electromagnetic Resilience Infrastructure'.

The following points identify the requirements:

- According to [20] the starting point is to identify what we are looking for! Example: unauthorised, unlicensed wireless devices, new wireless services turning on in an area of interest, keeping up with changes in the spectral landscapes. Furthermore, a signal development environment is required to; a) enable rapid development, test, and optimisation of signal (or device) detection and isolation capabilities; b) utilise commercial tools and software; c) can be setup in a secure or open environment; d) can be configured as portable, rugged, or transportable system. In essence for EMC the basic question to answer is there a frequency plan and should frequency plan be statutory for cities with buildings of interest (civilian infrastructures etc.).
- [21] Created a European project based on two phases: phase 1 consisted of assessment scenarios concerning IEMI - intentional malicious generation of electromagnetic energy introducing noise or signal into electric and electronic systems, NEMP – an electronic pulse produced mainly from gamma rays from a nuclear explosion, HEMP – a series of electromagnetic waveforms generated from a nuclear detonation at altitudes above 30km and the propagate to the earth surface, **and HPEM which produces intense electromagnetic radiated fields or**

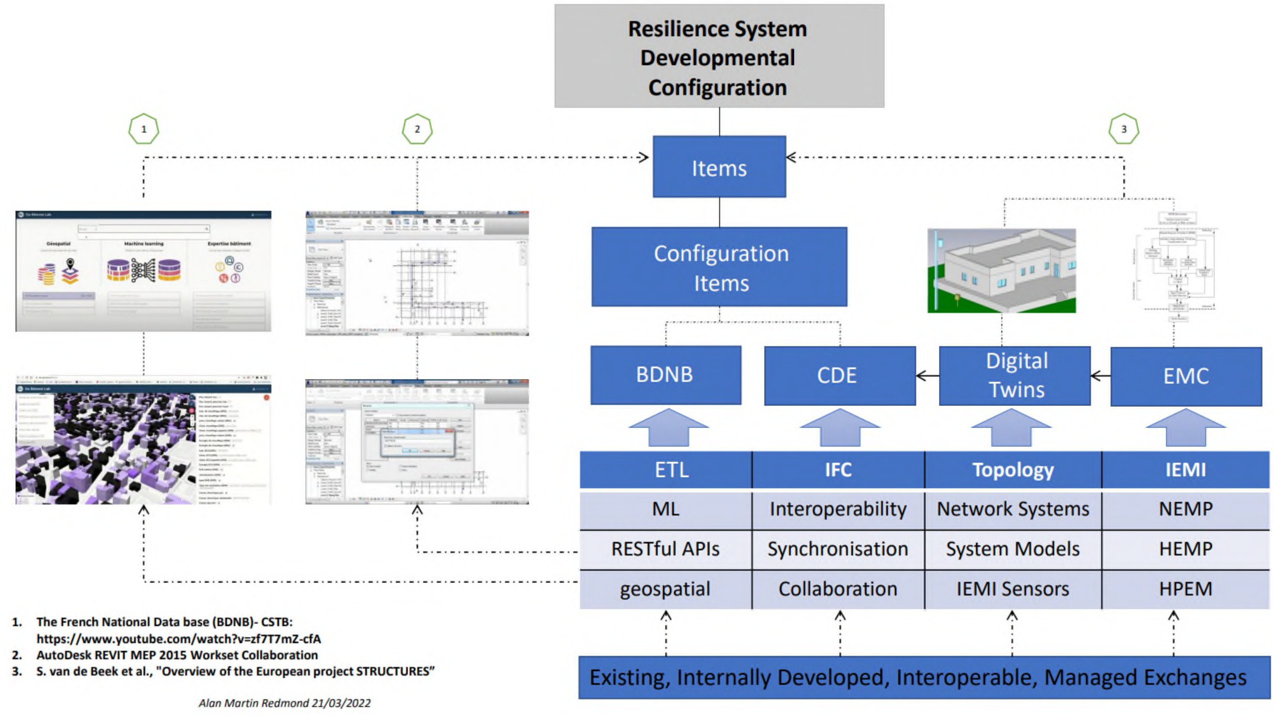

Fig 3. Resilience System Developmental Configuration Architecture, Legend: Common Data Exchange (CDE); Extract, Transform, Load (ETL); Machine Learning (ML); Application Performance Interface (APIs); Industry Foundation Classes (IFC); Intentional ElectroMagnetic Interference (IEMI); Nuclear ElectroMagentic Pluse (NEMP); High Altitude Electromagnetic Pluse (HEMP); High Power ElectroMagnetic Pulse (HPEM)

conducted voltages and currents with the capabilities to damage or upset a city infrastructures. Phase 2 investigated IEMI risks and introduced protection strategies based on sensor design, characteristics of susceptible devices and simulation tests.

- Figure 3 illustrates such requirements under the EMC column. Investigating such requirements can be enacted and enhanced via Digital twins, while interoperability as previous identified will be provided through Common Data Exchange (CDE) using IFC (BIM open data exchange files), under point 2 Autodesk in the diagram it shows how collaborative workstations are implemented in modeling design and this type of collaboration allows various actors/stakeholders to review the model sections referring to their needs and any changes can be synchronised to a central sever, or unsynchronised and shared as an independent file.
- The French National Database (BDNB) is a database built by joining multiple building-stock databases, including energy performances diagnostics, and energy consumption. BDNB concentrates on the Extraction, Transformation, and Loading (ETL) that refers to collecting raw data from disparate sources, transmitting it to a staging database for conversion, and loading prepared data into a unified destination system. This allows all the previous disjointed databases to be consolidated into a centralised system where analytics and calculations can be performed [22].
- The concept is to build upon [21] and create at national (French) and European level a centralised database that monitors HEPMs for civilian infrastructures.

C. Funding

To take the project forward will require a partnership built on trust and mutual respect. Securing funding for such research will be an onerous task. However, there are existing funding mechanisms such as HORIZON EUROPE – Work Programme 2021-2022 Digital, Industry and Space. Other funding mechanisms include the European Defence Fund – EDF (information superiority and disruptive technologies) and the European Defence Industrial Development Programme (EDIDP) which has five priorities:

- Facilitating operations, protection, and mobility of military forces.
- Information, secure communications, and cyberspace.
- Ability to conduct peak operations.
- Innovative defence technologies and SMEs.
- Innovation in defence research in materials

Actions of finance:

- Development of CBRN threat detection capabilities or anti-drone systems.
- Development of the next generation of precision ground strike capabilities, ground combat capabilities, aerial warfare capabilities and future naval systems.
- Solutions in the field of artificial intelligence, virtual reality and cybertechnologies.

VIII. Conclusion and Future Work

The papers' main objective was to illustrate a process model based on Developing European Defense Strategy for Electromagnetic Resilience Infrastructure Network. The paper highlighted the need/background for such a strategy by examining existing international strategies of reasoning such as the DoD Congressional Research Service Report that outlined the use of EMS. The capabilities of electromagnetic waves and how the infrastructure for supporting such emissions is protected such as **Data Centres and 5G Networks** is the background of the paper. The paper has also addressed KETs such as photonics in particular reference to Si photonics with CMOS electronics and bandwidth challenges. However, advancements in how we use standards to design a process that will achieve EMC taking into consideration EMI, needs to be addressed and function as part of an overall EMS strategy. The paper has outlined potential solutions such as the project must build upon existing networks and create similar Special Interest Groups (SIGs). The paper identified opportunities, risk and challenges and presented opportunities and the added value associated with utilising EMS, security, speed, energy and cost. In essence, the paper is a medium for identifying research opportunities within the scope European Defense Strategy for Electromagnetic Resilience Infrastructure Network.

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