MODERN SYSTEMS 2023

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Valencia, Spain

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MODERN SYSTEMS 2023

Forward

The International Conference of Modern Systems Engineering Solutions (MODERN SYSTEMS 2023) continues a series of events focusing on systems development considering the variety of combination between requirements, technologies, and the application domains. The conference was held in Valencia, Spain, November 13 - 17, 2023.

We are witnessing a paradigm shift in systems engineering approaches caused by several facets of society and technology evolution. On one side, the mobility, the increase in processing power and the large storage capacity created the capacity needed to deliver services to everybody, everywhere, anytime. On the other side, new computation approaches, data gathering, and storage combined with advances in intelligence-based learning and decision-making, allowed a new perspective for systems engineering.

The advanced pace of technological achievements is supported by Cloud/Edge/Fog-based computing, High Performance Computing (HPC), Internet of Things (IoT), Big Data, Deep Learning, Machine Learning, along with 5G/6G communications (integration of terrestrial/special systems) and mobility. As such, deployment, operation and technologies, integration, maintenance became a cornerstone for developing systems complying with functional and non-functional requirements.

We take this opportunity to thank all the members of the MODERN SYSTEMS 2023 Technical Program Committee as well as the numerous reviewers. The creation of such a broad and high-quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and efforts to contribute to the MODERN SYSTEMS 2023. We truly believe that, thanks to all these efforts, the final conference program consists of top quality contributions.

This event could also not have been a reality without the support of many individuals, organizations, and sponsors. We are grateful to the members of the MODERN SYSTEMS 2023 organizing committee for their help in handling the logistics and for their work to make this professional meeting a success.

We hope the MODERN SYSTEMS 2023 was a successful international forum for the exchange of ideas and results between academia and industry and to promote further progress with respect to modern systems. We also hope that Valencia provided a pleasant environment during the conference and everyone saved some time for exploring this beautiful city

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Antifragile Cities – Decision Support Tools to Support the Implementation of the Climate-neutral and Smart Cities

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Abstract*—Urban systems and cities are complex ecosystems continuously challenged by a wide range of environmental, health, social and economic stressors. This paper will identify an ensemble of models, methods, tools, and a framework that gives a geographically and operationally diverse set of data and information to cities, when they need it, and the intelligence to anticipate potential stressors and inform decision-making, to help them learn and capitalize on emergent situations and implement new mobility measures. The paper will present an innovative framework that: a) Recognizes when an event may disrupt the existing urban equilibrium; b) Manages the short-term effects of the mobility disruption to maintain safety, innovation, and city operations; c) Examines and simulates potential scenarios for future growth while adhering to the EU sustainability and CO2 reduction targets; d) Proposes an optimal new path forward that optimizes the improvements in the urban mobility landscape, while ensuring public acceptance and rapid adoption. The implementation of the methodology will result in improved urban space utilization, elevated quality of life, and enhanced sustainability and resilience in long-term urban development plans. This research acknowledges the necessity for robust decision support tools in realizing Climate-neutral and Smart Cities, making the AntifragiCity Framework an essential instrument in urban resilience management.

Keywords*— *Mobility and transportation, antifragile, homeostasis, black swans, decision-support systems

I. INTRODUCTION

Crises can have long-lasting and sometimes irreversible effects with local and/or global impacts. Most importantly, cities transitioning out of these crises struggle to recover their state of equilibrium, exacerbated by a sense and perception of uncertainty. This paper introduces the AntifragiCity Framework, a strategy that not only aims for resilience but goes a step further to seek enhancement from adversity, by treating cities as adaptive systems rather than static entities. However, they also note that the infinite variety of future threats cannot be adequately predicted and measured [1]. In recognition of measures, Gallotti et al. emphasized that attributes relating "to health and wellbeing of communities to urban structure and function, from traffic congestion to distinct types of pollution, can be better understood considering a city as a multiscale and multilayer complex system. The solution is to Rethink Cities that involve citizens in codesigning the city where widespread adoption of good practices leading to emergent effects with collective benefits, which can be directly measured" [2]. In the midst of this uncertainty, cities face a mobility reorganization – Electric Vehicles (EV) and their relevant infrastructure, teleworking growth, and a massive energy crisis are all contributing factors. Challenges of Urban Mobility (UM), such as the growing motorization in our cities has led to an increase in traffic congestion, noise, carbon emissions and concerns about road safety, resulting in social, environmental, and economic consequences. Black swans ("A black swan is a highly improbable event with three principal characteristics: It is unpredictable; it carries a massive impact; and, after the fact, we concoct an explanation that makes it appear less random, and more predictable, than it was" [3]) has disrupted the operational hypotheses and status quo (business as usual scenarios) for resilience thinking. This paper's core concept Antifragility is beyond resilience as the "resilient resists shocks and stays the same; however, the antifragile gets better" [4]. Drawing from this concept, the AntifragiCity Framework seeks to fortify cities by giving them the tools they need to anticipate potential stressors, learn from emergent situations, and implement new mobility measures that are not only environmentally sustainable, but also promote social equity and economic viability. The paper will create an ensemble of models, methods, tools, and a framework that gives cities the data and information they need, when they need it, as well as the intelligence to anticipate potential stressors, and inform decision-making, to help them learn and capitalize on emergent situations and implement new mobility measures. In section 2 objectives and ambitions are fully discussed.

II. DESIGNING INCLUSIVE, SAFE, AFFORDABLE, AND SUSTAINABLE URBAN MOBILITY OF USE

Within this article, we discuss the AntifragiCity framework, a strategy that uses antifragile principles to mitigate the impacts of mobility disruption, ensure safety, foster innovation, and improve urban mobility landscapes over time. AntifragiCity's overall aim is to pave the way to a new UM governance approach that enables cities to understand their business-as-usual modus-operandi (defined hereafter as their state of equilibrium) and to monitor (near) real-time continuous stressors and deviations from this state, assess potential implications through a simulation and prediction capability, inform adapted decision making to mitigate their consequences, while continuously enhancing their overall sustainability and resilience.

A. Objectives and ambition

The overarching aim of this potential decision support tool translates into the following 4 objectives formulated alongside the framework as shown in Figure 1.

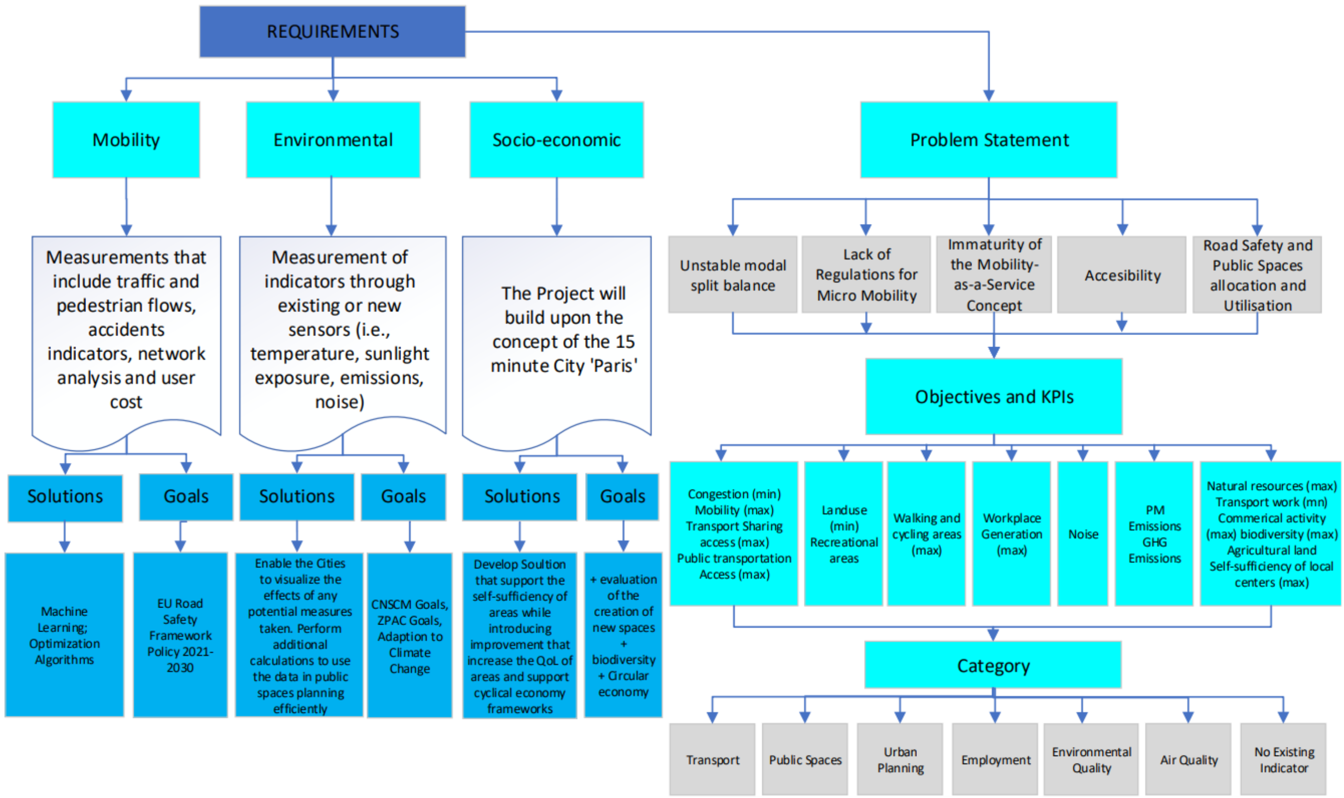

Figure 1. AntifragiCity Conceptual Framework.

OBJ1: Specify, assemble, and deliver a simulation, prediction, and decision-making environment, namely Simulator for Urban Mobility Antifragility (SUMA), Platform as a Service (PaaS), dedicated to UM management, while factoring in wider environmental, social, and urban planning considerations. The main goals of the Platform are to model the urban environment, the flow of different modes of transport, users' behavior, and incorporate them to tackle the UM problems.

OBJ2: Create an event ontology, including a taxonomy, to characterize (near) real-time endemic and acute events and their associated risks in an urban and wider regional landscape. The ontology will provide context to sensory data and social media information acquired across urban areas, and will serve as a basis to simulate, predict, and inform decision-making.

OBJ3: Develop a (near) real-time response capability to sense deviations from the urban equilibrium state and propose mitigation measures to counter potential risks, using the concept of mobility triage to enhance resilience.

OBJ4: Deploy the proposed AntifragiCity models, methods, and tools (i.e., SUMA) across selected unsafe areas and assess their progress beyond the current business-as-usual modus-operandi, using adapted Key Performance Indicators (KPIs).

Table 1 explains the various techniques that will be applied to each objective and its evaluation defined through measurement. "Measurement supports realistic planning, provides insight into actual performance, and facilitates assessment of suitable actions" [5].

TABLE I. METHODS & MEASUREMENTS

OBJ	*Methods*	*Measurement*
OBJ 1: SUMP	Devise innovative, reliable, and efficient solutions for the movement of people by taking different user profiles and their behavior into account; Deploying the models, methods, and tools, developed as part of SUMA across the demonstration projects	Develop decision-making mechanism with dynamic risk-based prediction incorporating cutting-edge forecasting models continuously augmented with real data
OBJ 2: Ontology	Corroborate and make sense of sensory and social media data and information real-time, using a combination of machine learning and natural language processing algorithms; Rely on the AntifragiCity ontology that elaborates on potential risks based on historical information and state-of-the-art literature.	Develop forecasting models that leverage sensory and social media data and information; Develop forecasting risk models that leverage sensory and social media data and information.
OBJ3: Real-time senses	Improve road infrastructure safety by redesigning the hierarchy of road system based on the need of speed limit. Appropriate measurement of data of traffic volumes and modes that are important	Re-assess and re-design road infrastructure system. Share of micro-mobility vehicle parking in dedicated parking areas (e.g. micro-mobility-hubs).
OBJ4: Models	The methods used for the environmental assessment are based on the performance approach (versus means approach) to	In situ sensors, to "reduce air pollutant emissions" and "decrease noise hindrance". • Dynamic Life Cycle Assessment

OBJ	*Methods*	*Measurement*
	cover the goals of the climate change mitigation and adaptation, the biodiversity preservation, and no net land take. Thus, the environmental performance of implemented solutions (e.g., increase the green area and bike lines, better communication, etc.), will be assessed	(DLCA) method, to "Reduce greenhouse gas emissions". • Biotope Area Ratio/Factor (BAR/BAF) method to "reduce impacts on global biodiversity & enhance local/in-situ biodiversity" and "Optimise the urban area/land use: contribute to the no net land take goal".

B. The scope and requirements

AntifragiCity Framework adopts a socio-technical approach where citizens, including transport users and commuters, are active, as opposed to passive, agents in the UM landscape. Citizens can share and provide feedback about their mobility experience, which is then factored into the decision-making process.

This feedback includes qualitative (social media) as well as quantitative data that will be integrated with the urban sensory data streams to provide a holistic and accurate account of the transport situation to maximize co-benefits across the mobility value chain. Furthermore, AntifragiCity's resilience approach is nature-inspired, with a focus on homeostasis ("Subjective Wellbeing (SWB) Homeostasis theory asserts that each individual has a set-point for their SWB, which is a genetically determined individual difference" [6]), but also incorporates antifragile and allostatic attributes for a more dynamic response to change. Lessons learnt during the period of imposition and lifting of Covid related restrictions, as well as other stressors and disruptions experienced by participating cities, will be analyzed and key lessons shared and factored into the decision support tool approach.

III. CONCEPT AND METHODOLOGY

AntifragiCity's vision recognizes that urban environments consist of multiple layers of complex and dynamic data from various systems and user groups. When captured, analyzed, and interpreted correctly in a timely manner, this data can significantly enhance the city's monitoring system, enabling real-time responses that present various opportunities. This approach allows for optimal management of city pressures, leading to improved immediate outcomes for citizens and helping update long-term sustainable development and resilience management plans.

A. Six-stage nature-inspired approach

The methodology approach to Antifragility resilience will involve a six-stage nature-inspired approach exploiting the concept of homeostasis, augmented with antifragile and allostatic attributes. Antifragility describes a system, which under stress or deviation from the normal, improves its overall state. Allostasis extends the antifragility of our urban systems when the city is under continuous stressors.

The first stage involves citizen engagement with a view of preparing the local population to the step changes that will be brought to the city via the planned demonstration project. Through the process itself, citizen participation can be used instrumentally to identify critical risk issues on developing and integrating infrastructural developments. The AntifragiCity Framework proposes participatory methods to be applied to explore public understanding, expertise, values, and preferences in respect of city systems integration and the underpinning governance models.

The second stage concentrates on developing an urban systems integration approach, which involves semantic conceptualization of urban systems. An integrated semantic representation of built, infrastructure, and mobility facilities across the 10+1 selected urban areas (including energy, transport, water, land use, IT, and health) is proposed to be developed, which will enable holistic system reasoning and analytics in a way that makes possible cross-sectoral

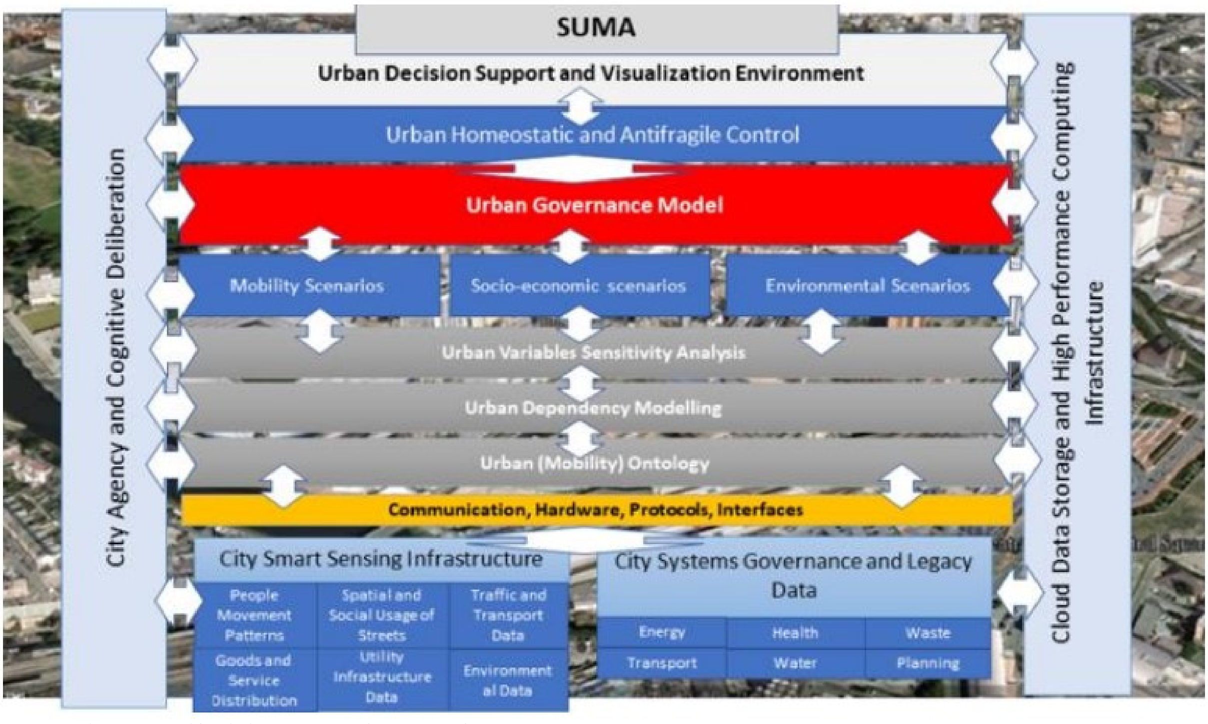

Figure 2. AntifragiCity Conceptual Framework

evaluation of changes / perturbations to city networks (including design, configuration, pricing, management, and governance). The resulting urban ontological referential can be used as a basis for reasoning on a city network interdependencies between infrastructure variables ranging from traffic flow intensity to public health indicators.

The third Stage involves the understanding and mapping of Technical, Commercial, Geospatial and Regulatory Interdependencies within each participating city. The decision support tool proposes to identify existing urban system analytical models unravelling governing variables and parameters where the analysis of system-specific flow network data models, can be done by using existing GIS techniques to determine each of the main 'flow' sectors: transport, and water. A conceptual framework for identifying governing risks of city system interdependencies will be developed with a view of promoting system adaptability and resilience.

The fourth stage will involve building a holistic and dynamic urban analytical modelling environment that incorporates the above understanding of inter-systems variable interdependencies and uses indicators to: (a) organize technical, socioeconomic, and environmental data to understand real-time urban system dynamics and interrelated impacts, and (b), aid in risk and impact assessment and city holistic informed decision making. The predictive models will be developed with a high degree of plasticity, allowing exploration of the influence of a broad range of socio-technical variables on system performance – e.g., the impact of different governance styles (markets, hierarchies, and networks) norms, and regulations.

The fifth stage will involve exploiting the semantic, dependency, and predictive models developed in the previous stages to deliver managed city systems with a decision-making capability that factors in decision criticality, implications, stakeholder, and citizen views, as well as security, confidentiality, and data sensitivity issues. A multi-layered architecture is proposed that delivers integrated city systems with a view of achieving adaptability and resilience. One of the innovative aspects of the framework is the reliance on the concept of agency (*cognitive and collaborative agents*) to provide an abstraction capability and interface to hardware and software components. The semantic layers 'machinery': City Ontology, dependency modelling and sensitivity analysis play a central role in interpreting actively requested low level data about the city integrated systems environment. Machine Learning (ML) approach and related functionality/service will be implemented whenever it is needed to handle the problem of missing data and produce predictive model control algorithms. The upper layer (SUMA PaaS) represents the user front-end that exploits all the above modules using adapted visualization metaphors to enable decision makers monitor and manage the performance of their city systems.

The sixth stage will be to explore the potential of different business models to promote efficient integrated UM and wider infrastructure systems, and develop tools for monitoring and evaluation by understanding the mechanisms, which enable mobile, domestic and community capital to be allocated to integrated infrastructure projects in an economically and environmentally efficient manner, and to consider effects of scale economies in gaining finance packages; developing a taxonomy of potential project ownership and control models for integrated infrastructure and outline their strengths and weaknesses in terms of impact on social, economic and environmental variables; understanding how transitions might occur from existing forms of project ownership and control to those, which permit greater levels of local resilience and local determinism in the process; and to develop understanding on how city systems can be developed and how processes will be adopted, which will optimize understanding of the trade-offs between economies of scale, financial cost, social equity and environmental impact.

B. The AntifragiCity Urban demonstration activities

The AntifragiCity demonstrations should aim to support cities in achieving the goals of the Climate Neutral and Smart Cities Mission [7] through the development of an innovative working environment in which mobility solutions are developed based on a user-designed approach and are monitored and improved by the input of a sensor-supported monitoring system and citizen participation scheme. The methodology of the demonstrations follows the approach below:

- **User-centered design plan:** includes the user research and analysis of each demonstration, and the development of a detail plan to ensure greater value of the demonstration for its end-users, the citizens.
- **Living lab design:** This task contemplates 3 steps. First, the co-creation of the living lab design together with the end-users, second, the testing prototypes in SUMA and the users-testing, and third, the detailed design of the living labs, including the technical, legal, operational, and communication requirements of each living lab, together with the city specific KPIs to monitor the performance of the demonstration.
- **Preparation for the demonstration and monitoring system:** This task includes the implementation of the operational, legal, commercial/communication and citizen engagement activities identified by the cities' Living Labs design and user-centered design plan. In addition, it will include the setting up of the monitoring system, based on Internet of Things (IoT) technologies, for each Living Lab, to ensure baseline measurement and a Smart project monitoring.
- **Demonstrations:** User-centric innovations are implemented, and demonstrations will be conducted in each lead city. Physical and digital campaigns will be conducted to raise awareness of the innovations among citizens. Co-creation activities shall be conducted to receive feedback from citizens and stakeholders. Quantitative and qualitative data from citizens/users, stakeholders, network, and operations are collected through surveys and sensor devices as part of the monitoring process.
- **Assessment of the demonstrations:** The data collected in the monitoring system along with other data collected in the previous steps are used to assess the multidimensional impact of the implemented concepts. Comparisons can be made between the baseline and the implementation phase to assess changes in travel behavior, user satisfaction, modal shares, risk factors mitigation, emissions, noise, resilience, etc. Based on the lessons learned in the evaluation phase, a decision shall be made regarding the continuation of the living lab as is or the initiation of a new experimental cycle of co-

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creation (*agile approach to innovation*) to explore new ideas. Additionally, the evaluation will include a cross-cities impact evaluation and a transferability assessment.

C. Potential barriers and obstacles

Table 2 presents identified barriers and mitigation measures to secure AntifragiCity's impacts.

TABLE II. POTENTIAL BARRIERS & OBSTACLES

Barriers / Obstacles	***Proposed mitigation measures***
Dispersed regulatory framework and the need for cross-modal and cross-sectoral interoperability and commonly accepted standards	It is widely acceptable that there are important discrepancies in the regulatory framework governing, either at Member State, regional or even local level coupled with the need for cross-modal and cross-sectoral interoperability and the use of commonly accepted regulations and standards. They comprise of an innovation challenge that may affect the adoption of AntifragiCity's models at European-wide up-take framework. The requirement is to analyze these implications to adopt an approach that utilizes collective methods and tools that ensures the participation of all related stakeholders from an early stage to highlight and adequately discuss the respective implications from the design phase.
Implementation dependent of political decisions	AntifragiCity's proposed approach will involve stakeholders from different disciplines, from the design stage to the implementation stage. In particular, the participation of city authorities in the consortium, which have the political mindset to implement the proposed actions, that will ensure the successful implementation of the Decision support tool actions at pilot level.
Conservative mindset and lack of confidence in innovative solutions from the demand / consumer side	The decision support tool user-centric approach is designed to gather and analyze user intelligence, together with its co-creation approach that directly involves users as key stakeholders, ensures high user acceptance rates and is expected to confront any symptom of conservative mindset and lack of confidence in the proposed innovative solutions and services.
Capital intensiveness of innovation, reinforced by problems of financing	The innovative business models and services that will be co-created and proposed by the decision support tool will take into account *capital investment needs vs. potential funding sources*. Those will be further accompanied by a preliminary estimation of service implementation *costs vs. potential inflows for the value chain as a whol*e. The approach aims to ensure that the suggested innovative business models and services will constitute a financially viable and sustainable option for the targeted stakeholders, pre-describing and assessing potential financing sources at either public or private sector.

D. Assessing existing software to be incorporated into SUMA

The current technique aims to exploit existing technology and software developed in previous European research projects to structure the multimodal functionality of the Simulator for UM Antifragility (SUMA), in line with the proposed architecture. The combination of existing software will result in saving valuable resources from redeveloping already existing technology. The outcome of this assessment will be a cohesive analysis of the different available software that will be incorporated into the SUMA.

IV. BEYOND STATE-OF-THE-ART

The AntifragiCity Framework will progress current state-of-the-art in the following areas:

a) resilient urban areas,

b) land use and urban planning,

c) urban semantic models for mobility management,

d) reference architectures for mobility management, and

e) smart city platforms for UM.

A. Resilient urban areas

Resilient Urban Areas: Resilience is generally defined as the capacity of a system to withstand an external disturbance and **proactively recover towards a new stable state** [8] AntifragiCity decision support tool will progress state-of-the-art in the field of urban resilience by exploiting the nature-inspired concept of biomimicry, as exemplified by the natural phenomenon of homeostasis, representing the natural tendency towards maintaining a relatively stable equilibrium between the constituents of a complex system, as maintained by physiological processes, while acquiring an increased resilience. Such a concept will implement homeostatic interventions to bring deviation back to the setpoints and if such events create permanent issues in the city, an allostatic state will then be initiated.

B. Land use & urban morphology

Research shows that efficient planning of land use contributes significantly to resilience when dealing with urban development [9]. AntifragiCity will develop holistic approach to model the urban dynamics from a social (human-driven) perspective factoring in a wide range of variables. This model will assist local authorities in their planning process as well as their quest to transition towards inclusive, sustainable, and resilient (including from a gentrification perspective) urban areas. AntifragiCity will also provide services that incorporate the vulnerable road users dimension into infrastructure planning, including aspects of safety and security, accessibility, digital and smart tools for enforcing speed limits and vehicle access, design and operation or services and public spaces, including mobility hubs, public transport, and shared mobility.

C. Urban semantic models for mobility management

Semantic web technologies such as OWL ontologies introduce a common taxonomy to a specific domain and explicit real world concepts' interrelationships, which can ultimately help tackle data heterogeneity and facilitate information discovery [10]. Several ontologies in connection with urban sustainability assessment will be analyzed from literature (i.e., building structure, water quality or personal health information) [11]. For example, the Transport Disruption ontology that describes travel and transport related events, assessing their disruptive impact on mobility at the urban level [12]. These ontologies are examples of the efforts made in semantic development for urban sustainability or sustainability subdomain representation. However, none of these ontologies abstract the high-level concepts required by AntifragiCity, as the existing models provide a fragmented view of the whole domain. AntifragiCity will progress current state-of-the-art in UM modelling by developing an UM Ontology that factors in all aspects that underpin the Urban metabolism, thus providing a holistic approach for managing mobility.

D. Reference architectures for UM management

AntifragiCity will focus on aligning the existing discipline-oriented models to form a reliable and comprehensive multi-disciplinary reference model that will be used and progressed / enriched on a continuous basis. The decision support tool will extend the IoT stack architecture to include a semantic referential, in the form of an UM reference model, that extends City information models, such as City Geography Markup Language (CityGML), while factoring in security (including data governance) considerations. The decision support tool reference architecture will factor in social constructs to promote a participative approach considering the complete value chain, with a focus on UM. It will include an inference layer that is grounded in the semantic description of UM. This form of intelligence will be distributed, i.e., available on the cloud as well as on the edge, to address network latency and security issues.

E. Smart City Platforms for UM

The decision support tool will comply with OASC (Open & Agile Smart Cities), and promote interoperability between various urban artefacts, including mobility, through dedicated APIs to access data, and context information. It will also provide the capability to develop a semantic contextualization of data feeds originating from connected objects found in cities, in the form of model constructs aligned with the proposed UM semantic reference model. These extensions will be reusable across platforms. Furthermore, the decision support tool will integrate the principles of agency to deliver an agent-based platform, with an application for mobility and related areas. Finally, it will also develop security approaches that adopt the principle of least privilege while factoring in existing standards, such as ISO 19650-5 as well as a model-based governance approach taking into account the complexity of the urban metabolism.

V. Conclusion

This paper focused on a framework orientated on designing inclusive, safe, affordable, and sustainable UM. The proposed conceptual framework 'AntifragiCity' is based on the theory of antifragile whereby the city will resist short-term effects of mobility disruption, maintain safety, innovation and optimize improvements. Four specific objectives (SUMP, Ontology, Real-time Senses, and Models) have been identified with recommended techniques and measurements. The framework's adaptive process of maintaining resilience relating to Homeostasis theory through subjective well-being has been integrated into the methodology. The methodology has been presented in 6 phases that will support positive outcomes for citizens such as better use of urban spaces and increase quality of life, while updating the city's long term sustainable development and resilience management plans. A methodology for urban demonstrations was highlighted featuring recommended goals from the Climate Neutral and Smart Cities Mission. In acknowledgement to novel framework the paper addresses five beyond state-of-the-art requirements; a) Resilient urban areas – implementation of homeostatic interventions; b) Land use & urban morphology - develop holistic approach to model the urban dynamics; c) Urban semantic models for mobility management - progress current state-of-the-art in UM modelling by developing an UM Ontology; d) Reference architectures for UM management - a reference architecture that will factor in the complete value chain, with a focus on UM; e) Smart City Platforms for UM – it will comply OASC, and promote interoperability between various urban artefacts. In the opinion of the authors the development framework for 'Antifragile Cities - Decision Support Tools' is an essential tool to Support the Implementation of the Climate-neutral and Smart Cities.

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Evaluation of different Systems Engineering Approaches as Solutions to Cross-Lifecycle Traceability Problems in Product Development: A Survey

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***Abstract*— Requirements traceability is an essential Systems Engineering (SE) task that is critical in areas such as software development, product development, and safety engineering. It involves linking requirements to all system elements, including test cases, to improve test coverage, product quality, and communication among stakeholders. Due to limitations in SE approaches underlying traceability methods, this area faces challenges such as an imbalance between cost and quality or insufficient system understanding for different disciplines. In this paper, we examine several universal SE approaches for their efficiency in addressing traceability issues in product development. Through a literature review, we identified methods based on these approaches and evaluated their effectiveness in solving traceability problems. This survey demonstrates the potential of Generic Systems Engineering (GSE) based methods to address identified gaps by creating a universal system understanding. However, the modelling method and procedure concept used in these approaches requires the inclusion of test processes and the associated information for system testing.**

Keywords-System Engineering; Requirement Engineering; Traceability; System Test; Product Development.

I. INTRODUCTION

According to the definition of INCOSE (International Council on Systems Engineering), System Engineering (SE) is an approach that aims to enable system designers to capture and meet customer and stakeholder requirements for the system throughout its life cycle, through better traceability of issues and more efficient coordination in an interdisciplinary team [1]. This definition makes it clear that capturing, structuring, and implementing requirements for the system and its elements are also part of SE. Thus, "Requirement Engineering (RE)" is referred to as a subdiscipline of SE [1][2]. RE includes all activities necessary to elicit, analyze, and document (product and project) requirements. In the RE process, requirements are not only developed but also iteratively managed [3]. Thus, this process can be divided into two parts, i.e., Requirement Development and Requirement Management (RM) [4][5].

System requirements are constantly changing due to changes in the needs of system stakeholders (including customers), changes in the environment, changes in the business, changes in laws and regulations, etc. [4][6]. RM is primarily the process of controlling these "changes" to system requirements. In this respect, however, RM is facing new challenges. The current high level of globalization is closing to Enterprise Networks (EN) with multidisciplinary teams. A short reaction time to the changes and thus the fulfillment of customer requirements needs a more complex cooperation between the different internal departments as well as external companies [4][7]. Minimization of failure, adherence to schedules, and high product quality require not only a common understanding of the system design, but also information about the required quality standards and the current data situation among all team members [8]. Nevertheless, this cannot be realized without the creation of efficient interdepartmental data exchange mechanisms and communication capabilities or interfaces for recording information. An essential necessity is the capability to trace requirements in both retrospective manners (such as identifying the source of a requirement) and prospective manners (like associating test cases). In other words, traceability in a system should include the relationship between requirement and all system elements including **components**, **processes**, **functions**, and **test cases** [2][4]. Finally, in order to capture and map responsibilities for various system elements in the EN, the requirements and the above mentioned system artifacts should be linked to the responsible **persons** [9][10].

As mentioned above, requirements traceability should also be used to link requirements to test specifications and methods. It is important to know which requirement is covered by which test or test cases. In addition to mentioning important benefits of merging requirements and test cases, Kukkanen et al. have illustrated the important relationships between the processes of RE and System Testing (ST) in their work [11]. In [12]-[15], further advantages of linking requirements and testing are mentioned.

A. Traceability Challenges and Problems

Requirements traceability can be influenced by several factors. Ramesh identifies three factors that affect the implementation of requirements traceability in a company, namely the environment (technologies), the organization (business strategies), and the context of system development (policies, people) [16]. These three factors can in turn be divided into two coarser categories of **methods** and (tracing) **tools** [17][18].

Appropriate and practical methods are needed to track requirements, including their linkage to test methods, which at the same time allow a cost-quality trade-off [19]. Graham has also identified the absence of the physical end system prior to the development and planning of the test methods as one of the seven problems in linking requirements and testing [20]. The development process of complex meta-systems or more specifically “system of systems (SoS)” consisting of various components, is an interplay of various specialist disciplines. Here, in addition to bringing these disciplines together and linking the respective experts for the purpose of smooth communication and information transfer, methods and measures are also required to master the complexity of the multi-structural design of the overall system for effective uniform system understanding among the stakeholders [21]. However, such standardized procedures with a trade-off between cost (including time) and quality for analyzing requirements and translating them into a clear model do not yet seem to be widely used in industry [14][22]-[26].

Finally, the appropriate model-based method should be implemented in a computer-based tool, namely tracing tool, which plays an important role in the context of traceability [27]-[29]. A lack of suitable tools also leads to a mismatch between requirements and customer needs, which affects customer satisfaction with the final product [30]. Nevertheless, the efficiency of traceability and thus RM in the state of the art is limited due to lack of tool support [11][12][16][24][25][31]-[37]. The willingness of corporate employees to learn and use the tool depends heavily on the degree to which the tool is user-friendly [17]. This can be a particular barrier for Small and medium-sized enterprises (SMEs) that have limited infrastructure for using complex tools and organizing the necessary training [38]-[43].

The above factors show the need for a method that improves system understanding through an appropriate metamodel in an efficient and cross-lifecycle manner, as well as a smooth flow of information in EN through a powerful tool. This is exactly the main goal of SE mentioned earlier in this paper, where the system model should not only enable an interdisciplinary product view, but also support communication and cooperation between users and provide a link between different system data [10]. By linking the system model to a procedure concept, SE is also intended to represent the temporally logical linking of problem-solving steps to solve a complex task. Nevertheless, due to limitations in SE approaches underlying traceability methods, the identified challenges remain unsolved. The main problem is the loss of the original idea of SE over time, i.e., the merging of different disciplines due to the increasing focus on specific areas instead of universality of methods [44]. This can degrade communication in a multidisciplinary team, for example between requirements and test engineers, which is one of the important problems of traceability. In addition to briefly presenting various SE approaches, the following part introduces some of these constraints.

B. Different SE Approaches

The approaches developed for SE can be categorized as either universal or specific [45]. The specific SE approaches, e.g., for software engineering focus on their own disciplines and not on the universal transdisciplinary use that should characterise SE. This makes it difficult to communicate between disciplines and to identify commonalities in their methods. The methodological differentiation of such approaches hinders transferability between different product domains and slows down the product development process [46]-[48]. However, this is of great importance for the development process of meta-systems, which represent a multitude of different technical subsystems from the various domains, as mentioned above.

The universal approaches can be divided into System of Systems Engineering (SoSE), Model-Based System Engineering (MBSE) and Generic System Engineering (GSE) [49]. Various descriptions of SoSE or SoS have been produced in the literature, but to date there is no universally accepted definition [50]-[54]. In the absence of a general system definition, the domains, relationships and attributes cannot be represented in a uniform way, which hinders the creation of a unified system model [45].

INCOSE defines Model-Based Systems Engineering (MBSE) as a "formalized application of modelling to support system requirements, design, analysis, verification, and validation that begins in the conceptual phase and extends throughout development and later life cycle phases“ [55]. Within the context of MBSE, numerous modeling languages are utilized. In practice, the models based on the "Unified Modeling Language (UML)" and "System Markup/Modelling Language (SysML)" have become the most popular in the MBSE application. These are capable of representing the relationships between system elements and requirements, but exhibit a high level of abstraction, primarily stemming from their limited graphical notation [56]. Moreover, this approach lacks interaction between the system model and the procedure model at each step of the development process. This is of course needed for updating the system model as well as for traceability of elements over time, as dynamic environmental factors need to be taken into account [2][57]. According to Morkevicius et al. many methods in the context of MBSE remain too abstract for solving concrete real-world problems because they do not provide a framework for organizing the modelling work [58]. Such methods show a mismatch between the model created and the expectations of customers, as understanding the system is difficult for different stakeholders due to the high model complexity [59]. Another limitation of MBSE methodologies is finding a common language for defining stakeholder needs and bringing together a wide range of stakeholder views into a single model [60][61]. In addition, INCOSE cites inherent difficulties in integrating models across organizational, lifecycle and other boundaries, and limitation of model/data sharing capabilities within modelling tools as other problems of MBSE [55][60][62]. Moreover, the high implementation costs of MBSE approaches compared to traditional SE approaches and the still limited life-cycle management tools for managing MBSE models [59][62]-[65] can be particularly challenging for SMEs. In the case of highly complex technical systems, the lack of a transdisciplinary focus and the difficulties in managing a large amount of generated data are further problems of the MBSE approach [2][66].

"Generic System Engineering (GSE)" developed by Winzer and Sitte [67] is considered a state-of-the-art and proven approach that satisfies the new dimensions of complexity, thus reviving the lost original universal approach of SE [45][46][49][57]. GSE proposes a common thinking model to derive a unified system model. For this purpose, it consists of a standardized approach divided into the "analysis" (problem identification and system analysis), the "target definition" (problem localization), and the "design" (recommendations), which can be problem-specific [46]. GSE standardizes SE in both system modeling and approach. GSE is thus a general problem-solving framework that provides different modules and a system model to ensure adaptation to a variety of specific problems [2][46][67]. One major advantage of the GSE approach over MBSE and SoSE is the clearly defined interface to project management [44][68]. This can contribute to a fast response to changes in system design or properties.

There are many different methods for building the system model for the technical systems and collaborative SoS in GSE, including Demand Compliant Design (DeCoDe), which provides a technique for system definition, description, modeling, and progressive refinement. The four views of the DeCoDe product model, i.e., requirement, component, function, process, are related to each other via a matrix to describe technical product systems [69]. An "enhanced Demand Compliant Design" (e-DeCoDe) integrates the social level of the SoS into the model through a fifth person view and thus enables the capture and mapping of responsibilities for different system elements in the EN [9][10]. All e-DeCoDe elements can also be represented hierarchically, with the requirements view. The unified matrix representation of the system in e-DeCoDe model can improve the understanding of the system for different disciplines by representing the system and the interaction between its elements in a simple but comprehensive manner. The low level of complication of the modeling method can be a promising factor in reducing implementation costs, as less training is required. Compared to the other modeling approaches, e-DeCoDe provides a clear delineation between system and environment and methodical handling of requirements in EN [44].

After introducing the different SE approaches and their general strengths and limitations, the different traceability methods offered in the state of the art according to the introduced universal SE approach will be surveyed in the next sections. Section II explains the methodology used in this research. Finally, the identified papers are evaluated and summarized in Section III.

II. Research Design

In this section, the aim of the study is formulated. In addition, the research questions and the methodology of the literature review are described here.

A. *Objective and Research Questions*

In the last section, traceability challenges were divided into two broad categories: Tools and Methods. Here, the necessary training costs for the tools and their limited functionality are the subordinate problems of the first category, i.e., traceability tools, while the trade-off between cost and quality of the approaches resulting from the complexity of the methods belong to the second category. Therefore, the objective of this work is to evaluate the existing methods in terms of their efficiency and the applicability of the tools used. This goal will be concretized in the form of different research questions (Q).

Q_1: Which approach is able to define the system more comprehensively by covering the different views of it (e.g. requirements, processes, etc.) including its socio-technical levels?

Q_2: Which approach is focused on managing complexity through a generic modeling methodology applicable in transdisciplinary teams?

Q_3: Which approach establishes the link between requirements and testing to improve RE and ST processes?

Q_4: Which approach has a structured procedure concept connected to the system model that maps the lifecycle of a system from requirements elicitation through design and construction to testing?

Q_5: Which programs are used to implement traceability methods and how do they contribute to reducing complexity?

Q_6: To what extent is the necessary information available to the system developer during requirements elicitation, system design and testing integrated into the implemented approach?

B. *Methodology*

By analyzing the current developed SE based methods to digital requirements management, including traceability in product development, the practical potential of the different approaches can be overlooked. The focus of these evaluations is on the ability of these approaches to robustly link test methods and requirements, as well as other key system elements, manage complexity and enabling system understanding across a multidisciplinary team. At the same time, the implementation of the method and the level of integration of the system data and information into an appropriate functional tool will be examined. Based on the challenges identified in Section I and the derived research questions in Section II, six different topic areas (T) to be considered are defined. The derived topics serve to more clearly distinguish these methods from the others and to better highlight the scientific gap. Subsequently, a literature review is conducted in December 2022 considering the following narrowing of the subject:

- Only the application of SE in the field of engineering is considered.
- Of these, only the methods from the field of product development are then considered.
- Of the various SE approaches applied in product development, only the universal SoSE, MBSE and GSE based methods are considered and analyzed.

The research is conducted via scientific databases such as GEPRIS, Google Scholar, IEEE Xplore, ScienceDirect, and SpringerLink during the observation period from 2015 to 2022. Based on this, 26 international and 4 national research projects or papers are picked out. Finally, the identified researches are evaluated based on the six topic areas. The methodology of the literature review is shown graphically in Figure 1:

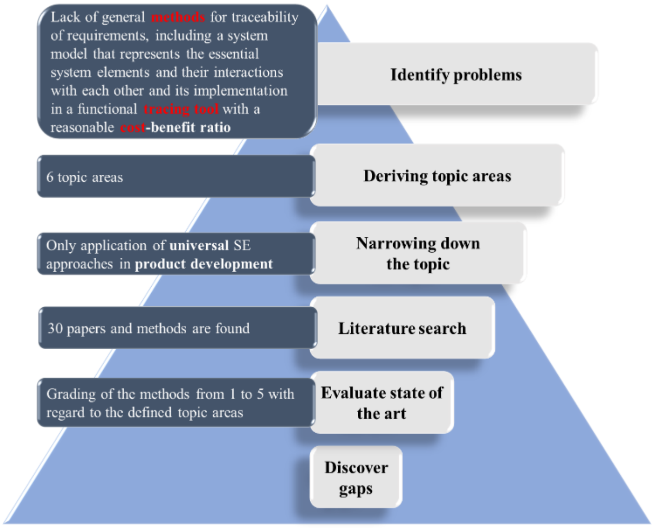

Figure 1. Graphical representation of the applied methodology in the present paper.

Based on the stated challenges and required solutions for each topic area, the studies were scored from 1 (lowest score) to 5 (highest score), with specific point awarded for each need covered. The important issues and needs for which a specific score was given are underlined in the following description of the topics with the corresponding score in parentheses. The assessment of the tools used in T_5 is based on [63][70]-[72].

T_1 (System Definition and Delimitation): The approach developed shall primarily address the linkage of requirements *(1p)* to key system parts and artifacts, including processes *(1p)* and components *(1p)*. Functional requirements shall be linked to the corresponding functions *(1p)* that the system is intended to perform. The approach should provide a clear boundary between the system and the environment and methodically support their interaction. To enable the treatment of requirements in EN, the approach should also include roles and liability through a person view *(1p)*.

T_2 (System Modeling): The developed approach should consist of a model that graphically establishes a linkage *(1p)* between the above-mentioned system elements. Generality, comprehensibility and universality of the model should be observed as well *(1p)*. By representing the interactions between these artifacts, the unified model shall enable traceability of requirements during the system development life cycle *(1p)* while handling system complexity *(1p)*. In addition, the model shall account for independent attributes and represent EN in a unified manner *(1p)*.

T_3 (Integration of Test cases): The importance and benefits of linking tests to requirements have already been explained in this paper. The model developed should be intended to enable the integration of test specification and methods by providing a link between requirements and test cases *(1p)*. However, this should not lead to an increase in system complexity *(1p)*. The important relationships between the RE process and the ST process shown in [11] should also be included in the model. In particular, these relationships include data on changes made or to be made to the requirements (0.5p) or test cases (0.5p), comments on the requirements design *(0.5p)*, test results *(1p)*, and information on defects resolved *(0.5p)*.

T_4 (Structured Procedure Concept): In addition to the comprehensive generic system model, the developed approach must include a structured procedure concept *(1p)*. The procedure model should have an iterative periodically recurring form *(1p)* and also represents the time course of system development *(1p)*. This should be cross-lifecycle and include the development steps up to system testing *(1p)*. The procedure concept must also follow the rules of SE and should accordingly be modular and universally applicable *(1p)*. In this way, the procedure model can enable EN a company- and product-specific use of RE methods, as well as the tracing and specification of requirements [10].

T_5 (Model Implementation): As already mentioned, the model should be implemented in a suitable software tool to realize system modeling *(1p)*. The program must visibly and transparently represent the system elements and their interrelationships *(1p)*. In addition, it must have filtering and focusing functions that enable concentration on the essentials or certain elements and thus systematically reduce the complexity of the modeled system *(1p)*. Even more, the software must enable the time-logical arrangement of functions and processes *(1p)* as well as the storage of system states in order to be able to track phases of project management *(1p)*.

T_6 (System Information Integration): The most important system information, which is particularly relevant for tracing the test results and their corresponding product characteristics and requirements, shall be implemented with the model in the program or tracing tool. We have listed some of this information, which is shown in the Figure 2 *(each information 0.5p)*.

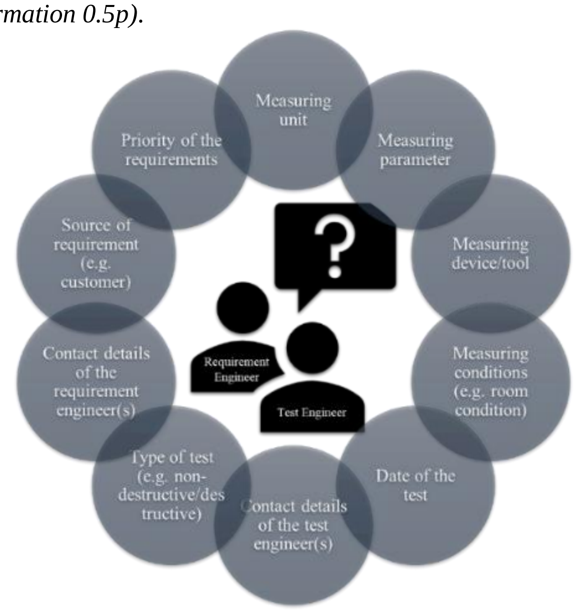

Figure 2. Important information for precise requirements and test engineering.

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This information, such as measurement parameters, contact details of the person responsible for the test, the measuring device used, etc., should be accessible in the program at all times. This allows the tracing tool to serve as a means of communication and information exchange for the parties involved in the requirement and the test. These information are to be implemented with the model in a practical program. Depending on the context of use, further information may be required.

III. Results

The results of the evaluation of the research works are listed in relation to their underlying SE approach in Table I. The results of the survey show the lack of a generic, cross-discipline RE approach that considers the linkage of requirements with testing. This problem has been solved in the developed GSE approaches, but the RE methods based on this approach do not consider the integration of inspection characteristics and procedures into the model as well as into the procedure concept. As discussed earlier, the SoSE-based methods seem to have the least ability to fulfil the identified demands, as evidenced by the results of this literature review. In general, the lowest score belonged to T_6 by all three approaches, which addresses the integration of the information listed in Figure 2 into the traceability tool.

TABLE I. EVALUATION OF THE STATE OF THE ART FOR REQUIREMENTS TRACEABILITY METHODS AND THEIR LINKAGE TO TEST CASES.

Evaluation		**Topics**					
Research \ Topic		**System Definition and Delimitation**	**System Modeling**	**Integration of Test Cases**	**Structured Procedure Concept**	**Model Implementation**	**System Information Integration**
No.	**Reference**	**T_1**	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**
MBSE							
1	[73]	4	2	3	3	3	0,5
2	[74]	4	3	3	1	3	1,5
3	[75]	5	3	2	2	3	0
4	[76]	4	3	3	0	3	1
5	[77]	4	3	2	3	3	1
6	[78]	5	3	2	3	3	0
7	[79]	3	2	1	4	5	4
8	[80]	5	3	2	5	4	1
9	[81]	3	2	1	4	5	4
10	[82]	3	3	3	5	3	1
11	[83]	3	2	3	5	2	3
12	[84]	3	3	0	2	3	1
13	[85]	5	3	3	3	2	2,5
14	[86]	4	3	4	1	1	2
15	[87]	3	2	0	0	3	1
16	[88]	5	4	3	4	3	4
17	[89]	2	3	0	1	2	2
18	[90]	2	3	1	1	2	1
19	[91]	5	1	3	3	3	2,5
20	[92]	4	2	0	2	4	0
21	[93]	4	4	4	4	3	5
22	[94]	4	4	4	5	2	4
23	[95]	3	0	0	4	3	1
24	[96]	4	4	3	1	5	1
GSE							
25	[97]	5	5	0	3	4	2
26	[98]	5	5	0	4	4	2
27	[99]	4	5	0	4	4	2
SoSE							
28	[100]	2	2	0	3	3	1
29	[101]	2	2	0	2	3	0,5
30	[102]	2	2	0	3	2	1

The highest score among the MBSE-based methods is achieved by Mandel et al. [93] with 24 scores out of 30, which not only shows a consideration of the system environment and its delineation from the system in the model, but also integrates a lot of information relevant for testing into the implemented model. However, the method does not consider roles. In addition, the procedure model does not fully include the steps for developing and managing the requirements [93]. Second among the highly rated MBSE approaches are the methods of Kremer et al. and Steimer et al., which both achieved a score of 23 out of 30. The presented method of Kremer et al. [88] used an iterative, overarching procedure model. In addition, the use cases and all major system elements are linked in the model. However, different tools were used to link and create the model, resulting in a tool chain in the end. In addition, the information relevant to the test could be more comprehensively included in the tool [88]. The MBSE-based approach of Steimer et al. [94] aims to better integrate production system planning with product development in the early design phases through a model-based planning process. This approach has an iterative V-model as a process concept. The authors pointed out that the method they developed makes models with a larger scale rather confusing. They also mentioned that the mostly abstract graphical representations in SysML, such as rectangles, circles and lines, require expert knowledge for their interpretation [94]. Pessa et al. [80] applied MBSE to an industrial test case to perform the functional design of an innovative control and maintenance system to be integrated into the aircraft fuel system. In their model, the requirements were linked to the use cases, but the system functions were derived directly by inferring the use dependencies between the system and the use case. The model shows the interactions between these elements, but gives no indication of the important data from the test process [80]. Bougain and Gerhard [81] have also developed a product development aid using SysML that helps designers make decisions using examples from previous or similar or other domains, including associated requirements, specifications, use cases, test cases, and other system information [81]. Huth et al. [85] presented an integrated approach that offers the possibilities of model-based requirements and variant modeling. In their work, in addition to test criteria, test cases, features, use cases and stakeholders, they have also linked the goals or targets with the requirements. However, a new sub-model, called the feature model, was created for modeling features, which affects the unified form of the model. In the presented procedure model is also no chronological sequence of the product development process recognizable [85]. The lowest point belongs to the work of Berges et al. [87], where an approach for coupling MBSE and simulation models was presented. The approach, which was exemplarily demonstrated on the development models for the virtual development of wind turbines, has a SysML system model that contains the relevant development information about the wind turbine and is linked to the simulation model in MATLAB Simulink to check the technical solutions for individual functions against the requirements. In this work, the focus is not on the universal representation of the system using the SE approach, but on the linking of the system model with simulation model for the purpose of subsequent automation of change processes [87]. In this approach the test cases are not integrated in the model as well as the methods in [84][92][89][90][95]. Moreover, it can be generally said that all observed MBSE-based methods exhibit high complexity, which complicates the understanding of the system due to the previously mentioned characteristics of MBSE.

The GSE based traceability methods evaluated in Table I offer a generic usability and a universal understanding of the considered systems. In [97], the authors presented an approach based on the e-DeCoDe model for consistent tracking of requirements from complaints. In this way, the identification of failure causes in product development is made possible. As a procedure, the authors developed a four-step process for deriving requirements from complaints. A new RE approach is presented in another work [98] based on e-DeCoDe that supports engineers in R&D Business Networks (BN) in a flexible and customizable way. This approach merges the three dimensions of RE, RM and BN into a structured procedure based on GSE, which enables a high level of understanding of the complex system, for the different partners in the EN. Finally, Bielefeld et al. [99] use the DeCoDe modeling method to analyze fault chains for a complex mechatronic system. In this method, organizational complexity is not considered and the focus is only on the technical complexity of the mentioned system [99].

The use of e-DeCoDe modeling based on the simple matrix format in [97] and [98] facilitates the understanding of the system by defining the essential system artifacts, i.e., requirements, components, functions, processes, and responsible parties. In addition, the interaction between the individual artifacts and the relationship between the system and its environment is captured in these methods. The tool (iQUAVIS) used for the implementation of the RE methods developed by Mistler et al. [97] allows the entire display to be filtered or narrowed to any system element, reducing complexity and providing a better overview of system components [97]. However, none of these approaches, nor any of the SoSE-based approaches explored, consider the linkage of the test methods with the system elements, including the requirements. This also means that the developed procedure concepts, despite their iterative modular structure, lack the relevant development steps for system testing.

IV. Conclusion and Future work

In this paper, we have presented the challenges in traceability of requirements and their linkage to test specifications and test methods. According to the studies, existing traceability approaches lack the appropriate methods and tools that offer a cost-quality balance in addition to an even understanding of the system and reduction of complexity.

Based on the aforementioned problem areas, we evaluated the different SE approaches, including specific and universal approaches, in terms of their potential for requirements traceability throughout the product development cycle up to system testing. In this context, the three universal SE approaches, i.e., SoSE, MBSE, and GSE, were presented as the most commonly used solutions for requirements traceability. In a next step, the different traceability methods available in the literature were evaluated through a systematic literature review with respect to their corresponding SE approach.

The results of the literature review show that MBSE enables traceability of requirements and their linkage to system tests, but they have limitations in terms of generic model structure, which limits the equal understanding of the system for the different stakeholders. In addition, some of the developed MBSE methods found in the literature review did not fully consider the important system elements, which should be connected with requirements. Some methods also did not take into account the person view, which enables social level interconnectedness in EN. The developed GSE-based methods that use (e)-/DeCoDe modeling provide a comprehensive view of the key system elements through a simple matrix view that keeps the model complexity low, but none of these methods consider the integration of the test processes into the system model. In addition, the necessary information listed in Figure 2 is not included in the tools used in most of the analyzed works. Compared to the MBSE and GSE approaches, the SoSE-based methods have reached the lowest score with regard to the observed topics.

Based on the identified gaps in the state of the art, we have started to develop an information pool as a data basis for tracing the requirements of a sample product (chemical protective clothing) using the GSE approach. In addition to integrating the system test into an e-DeCoDe model, our database should enable the capture of the system information in a suitable available software tool, e.g., iQUAVIS. Thanks to the integration of the person view in the e-DeCoDe model, this method can lead to a dynamic flow of data and information and an improvement of communication in the multidisciplinary teams. The unified structure of the e-DeCoDe model should allow for a better understanding of the system by different stakeholders without requiring a high level of training, which can be an important factor for SMEs. These benefits can be further explored and evaluated in upcoming research.

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Image Processing to Evaluate Post-harvest Damages on Grapes and Their Impact on Fruit Aspect

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***Abstract*— The interaction between grapes and fungi is a topic that recently has increased its interest since it can benefit or reduce fruit quality. Multiple factors determine the quality of grapes, which is directly affected by their ripeness, flavour, colour and overall health. In the post-harvest process, decay due to water loss and fungal decay are major challenges in grape quality and preservation. In this paper, we aim to develop an image tool capable of spotting anomalies in the skin of grapes using image processing and machine learning. A series of cameras connected to nodes identify irregularities on grape skin. Pictures are processed, and the results are sent to a database where the feature extraction happens. Data is sent to the cloud, where machine learning classifies the state of the fruit. In order to perform our tests, 2 bunches of grapes were studied for 14 days. One bunch had their skin punctured, while the other was left untouched. The metrics selected to evaluate quality detection were accuracy and recall. According to the results, the modules that represent the most accuracy and recall are K-Nearest-Neighbor (KNN), followed by Artificial Neural Network (ANN). In the case of KNN, when 4 parameters are included, the accuracy reaches 100 %. Following this same pattern, the ANN module rose an accuracy of 95 % when 4 parameters were added. In addition, in the recall metric, KNN spiked at 95 % with the incorporation of 3 parameters, while ANN escalated to 90 % by adding 4 parameters.**

Keywords*— *Fungal disease; quality; image analysis techniques; Machine Learning; disease detection.

I. INTRODUCTION

Grapes are known to be the primary source of many of the world's most popular wines, so understanding how to grow and cultivate high-quality grapes is essential for the wine industry and daily consumption [1]. Since it is such an important crop, the number of studies on this topic has increased in the last decades. Therefore, a vast number of studies have been focused on vineyard yields, specifically on the surrounding environment, climate, soil, and human interaction [2]. The quality is a property of the grapes, which might be strongly affected by time and is closely related to the presence of fungi. There are several aspects that can determine the quality of grapes, including their ripeness, flavour, colour, and overall health. During post-harvest, grapes are prone to rapid deterioration following harvest due to significant water loss from the drying of the rachis and pedicel. This dehydration leads to berry softening, weight loss, and browning [3]. In addition, significant losses are incurred due to fungal decay, primarily caused by necrotrophic pathogens. It has been studied that fungi have a rapid growth rate and can easily spread through berries, making their preservation challenging [4].

On the one hand, many reviews have described technological factors used to enhance the quality of grapes during the post-harvest stage [5]. Nevertheless, despite the need to improve methods for preserving the quality of table grapes during post-harvest, consumers are reluctant to use existing chemical treatments. Therefore, exploring and enhancing the physical processes during the post-harvest is important. The objective is to keep the grapes in environmental conditions that prevent the proliferation of fungi and water loss to keep the quality of the grapes [6].

On the other hand, monitoring systems based on sensors and image processing are being used in agriculture to identify fungal diseases and fruit quality. Nowadays, hyper- and multispectral imaging can be used to detect foliar symptoms of grapevine trunk diseases [7]. Additionally, image processing and Machine Learning (ML) techniques can be used to develop an automatic system for detecting grapevine diseases [8]. By doing this, it was detected that reflectance data could potentially serve as a means for evaluating crop damage [9]. Though, most research has been carried out on leaves rather than on the fruit itself. Nevertheless, as far as we are concerned, no papers focusing on the use of images for detecting loss of grape quality during the post-harvest due to the proliferation of fungi have been found.

The aim of the paper is to develop a tool capable of detecting anomalies in grapes by using image analysis techniques. To achieve this goal, 2 bunches of grapes were used. The first one was punctured, and the second one was left untreated. The process took 14 days before fungi appeared. During the study, 3 sets of photos were taken each day to observe grape and fungi development. The main novelty of this study was to cast aside molecular and chemical techniques to use a more visual and technological approach and apply it to the fruit instead of leaves. The process would be based on a camera connected to a node. This camera will take pictures to every grape bunch. Then, these images will be processed and detect the presence or absence of anomalies and an evaluation of their quality, informing the operator. Furthermore, this study will provide easier identification and presence of fungi in grapes.

The rest of the paper is structured as follows: Section 2 outlines the related work. The proposed system is fully described in Section 3. Following Section 4 details the test bench. The results are discussed in Section 5. Finally, Section 6 summarises the conclusion and future work.

II. RELATED WORK

In this section, we will summarise the current image analysis, the processing techniques used on leaves and the traditional methods for fungi detection and techniques to determine the quality of grapes.

A. Use of image analysis on leaves.

In [10], Meena et al. proposed the use of a Convolutional Neural Net (CNN) to classify picture pre-processing, image segmentation, and feature extraction in 5 different types of plants. By doing this, they analysed the colour, shape, and texture of the leaf and allowed them to locate the disease in the leaves. Similar to this study, Jaisakthi et al. [8] proposed an automatic system capable of identifying diseases in grape vines by analysing the leaves with image processing and machine learning. By doing this, they observed a difference between the possible diseases affecting the leaves.

The aforementioned examples show the use of image processing to analyse the presence of diseases in leaves and cannot be applied directly in post-harvest monitoring of grapes. These techniques can be applied in our case, but specific indexes or feature extraction settings must be adapted or developed.

B. Traditional methods for fungi and quality detection.

Among the methods to detect the fungi's presence, most of them are based on chemical and molecular techniques. In [11], Diguta et al. used a restriction digestion analysis of the Internal Transcriber Spacer (ITS) products. This is a relatively easy method that involves using biological procedures to digest the ITS products of the fungal isolation from grapes. Then, the resulting fragments can be analysed to determine and identify the type of fungi. This method is known to be rapid and reliable. However, it can only be used to study only filamentous fungi. On another note, additional widely used techniques are the DNA-based molecular methods. This involves studying the DNA of the fungi to identify them. For example, in [12], Zhang et al. isolated colonies from grapes by HPLC-FLD tests. They detected the production of certain toxins. Meanwhile, amplification products were analysed and compared with other sequences with PCR. In another study, Han et al. [13] tested microRNAs by extracting and sequencing RNA with a subsequent PCR to find resistance to a certain type of fungal disease. A similar study was developed by Zhu et al. in [14], where they studied fungal communities in the maturation process by using DNA extraction and amplification with PCR, purification, and analysis.

Regarding the methods for determining fruit quality, there are many sample-based laboratory analyses, such as PCR or DNA-based molecular methods. However, in 2017, Doerflinger et al. [15] proposed a digital image analysis that involves assessing berry quality using MATLAB programming language, providing an accurate description of berry quality. Kasimati et al. [16] used a machine learning-based data analysis technique. The use of ML algorithms to predict yield and quality has become increasingly popular in recent years.

Although these biological procedures are easy to repeat and conduct in the laboratory, it is essential to remark that technological tools are much faster and more efficient options. For example, direct observation and identification with sensors and cameras [17], [18] can provide a faster response than the aforementioned biological methods. Moreover, the biological procedures require specific equipment, reagents, trained personnel, damage the samples, and are time-consuming.

III. PROPOSAL

In this section, we detail the proposed system to analyse the grape skin in order to find the presence of anomalies. First, we present the system description, with details of all the different included devices. Subsequently, the used sensor and nodes are identified. Following, the architecture of the proposed system is depicted. Finally, all the image processing techniques are explained.

A. System description

The system consists of a series of cameras connected to nodes along the warehouse. The system aims to identify the quality of fruit and possible damages along the different parts of the treatment and packaging chain.

Sensor nodes will be programmed to capture pictures at specific time periods. Subsequently, these photos will be first processed in the edge, applying a vegetation index, and then sent to the database (DB). Then, in the DB, fog computing is performed to classify and segment the images. Moreover, in the DB, the feature extraction process is conducted. The obtained data is sent to the cloud, where ML is applied to classify the state of the fruit.

Regarding image processing, our system will be based on a mathematical combination of different bands. By doing so, we are able to identify between a healthy grape and an infected grape. Therefore, we will explore the differences in the values of healthy and infected grapes, emphasising on the fungi, and find mathematical functions that enhance these distinctions in the resulting bitmap image. This will be carried out by the node. Then, with the index, we are going to apply a reclassification. This will allow us to convert the original pixel value to a new value which represents a class. Following, image segmentation and feature extraction will be conducted. These steps will be done in the DB.

Tagged images are used for the classification of data with ML. The tagged data is based on the fruit colour and the existence of visible damage in the grapes.

B. Camera description

A camera that accomplishes the following requirements is needed for the proposed system. First of all, the minimum size for this application is 9024 x 12032 pixels with a vertical and horizontal resolution of 72 ppi. The RGB camera should offer a bit resolution of 24 bits.

The cameras should be placed at a maximum distance of 30 cm from the fruit. Flash will be used to ensure a homogeneous illumination in all the pictures.

C. Node selection

A Raspberry Pi 4 model B node is selected for this application. This node is used because of its high computational capacity compared with other nodes, such as Arduino Mega or EPS32. The selected node can perform some simple image-processing steps. Thus, edge computing can be included, reducing the required bandwidth to forward the data.

D. Architecture

The architecture of the proposed system can be seen in Figure 1. The network system is based on a series of cameras connected to the nodes, an Access Point (AP), a DB, and a cloud server. Cameras are connected to Raspberry Pi 4 model B microcontrollers that are able to identify and take photos of the grapes and apply the initial index. Then, the nodes forward the result of the index to the DB using a WiFi AP. The DB stores the data and performs some additional image-processing steps. The extracted features are sent to the cloud server, where the ML tools are applied to classify the grapes.

E. Image processing and ML classification

This subsection explains the different conducted processes for feature extraction of the captured images. The different steps include index calculation, reclassification, segmentation and feature extraction.

Concerning the index calculation, also known as band combination, we have used an existing index. The index was initially designed to estimate the chlorophyll content in leaves; nonetheless, it can be applied in this case to evaluate the greenness versus ripeness of the grapes. The index is named Green Leaf Index (GLI) [19] and is described in (1)

$$GLI = \frac{(2G - R - B)}{(2G + R + B)} \tag{1}$$

For image reclassification, a series of thresholds have been defined. The thresholds, based on the quartiles of the first processed image, can be seen in Table 1. After the reclassification, the new values range from 1 to 5 - the lower the values, the better the quality. The pixels from class 5 include areas of the grape with damages.

TABLE I. SUMMARY OF CAMERA FEATURES

Class	Original GLI	
	Minimum value	*Maximum Value*
1	-100	-1
2	-1	0
3	0	6
4	6	13
5	13	100

With regard to the segmentations, the centre of each grape is identified and a radial buffer of 125 pixels is generated. The included pixels in the circle are the analysed area of the grape, which are the included segments of the reclassified image.

Feature extraction consists of obtaining histograms of the different segments. The histograms will contain the number of pixels for each one of the pixel values, which can be 1 to 5. Thus, the generated histograms will include 5 classes.

The obtained data from the histograms are used for the classification with the ML module. For the classification, the segments must be tagged. An expert has classified the portions according to their colour and the presence of damages by providing two scores. The scores range from 1 to 5, the latter of which represents the lower quality. Then, an overall score is calculated by averaging both scores, which is an integer number. If the result of the mathematical operation is not an integer number, the next integer number is considered the result.

Finally, for the ML module, 5 alternatives are considered: Support Vector Machine (SMV), Discriminant Analysis (DA), ANN, Bayesian Network (BN) and K-Nearest-Neighbor (KNN). The selection of the most appropriate number of parameters for the classification is studied. The parameters are the values of the histograms obtained from the segments of the reclassified index, which are the 5 classes. A larger number of parameters will increase the accuracy of the system. Nevertheless, a greater energy consumption will be linked to the obtention of these parameters. Selecting the number of parameters, we balance the accuracy and energy consumption. Concerning the dataset, 6 pictures are used, and features were extracted from 12 and 13 areas of each picture. Thus, 75 areas are used in our proposal.

All the steps for the grape's classification are summarised in Figure 2.

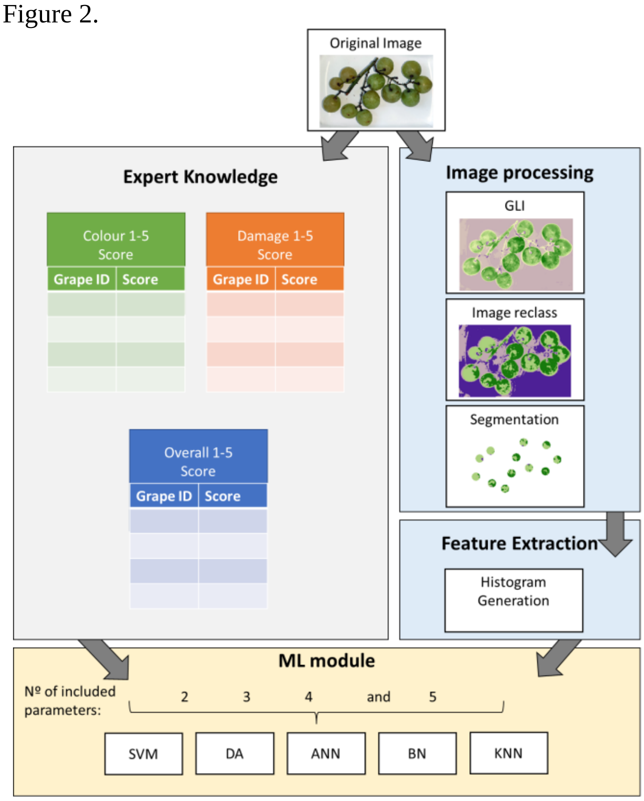

Figure 2. Summary of image processing and ML tools for the multimedia monitoring system for grape quality detection.

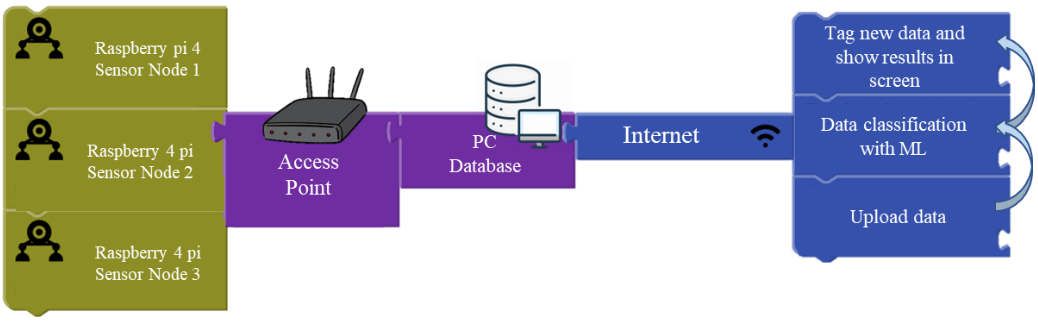

Figure 1. Architecture of proposed multimedia monitoring system.

IV. TEST BENCH

In this section, the complete test bench is detailed. First of all, the equipment and the image-capturing process is described. Then, the sample preparation is presented. Finally, the metrics employed to assess the results are shown.

A. *Equipment and image-capturing process*

In order to capture the images, a regular camera has been used. The camera lens corresponds to a sensor model with 108 Mpx, 1/1,33 inches in size and 1,66 µm pixels. Pictures were taken from a distance of 20 cm, and the flash was active in each case. Photos were taken 3 times a day, at 8 am, 4 pm and 12 pm, for 14 days. They were placed in two transparent plastic containers to prevent the grapes from being lost and to obtain a better study of their quality. A white filter paper was placed at the bottom of the compartment to simplify the process in the following image analysis. The dimensions of each receptacle were about 22x15x5 cm. These containers were selected with the objective of representing a similar situation as in real post-harvest. The grapes are carefully placed to avoid overlapping effects in this preliminary step.

B. *Sample preparation*

In order to perform our tests, 2 bunches of grapes were studied. All grapes were white seedless grapes, the variety Autumn Crisp. Each group had about 12-13 grapes, and all of them were attached to the stem. Both bunches of grapes were displayed in two compartments exposed to the air. The diameter of the studied grapes was around 2 and 3 cm.

To test the environmental influence and post-harvest quality, one bunch of grapes was left untouched, while the other had small punctures since day 1.

C. *Selected Metrics*

Two metrics are used to evaluate the performance of the different available ML modules. The selected metrics are accuracy (1) and recall (2), which can be seen below:

$$Accuracy = \frac{TP}{TP + FP} \quad (1)$$

$$Recall = \frac{TP}{TP + FN} \quad (2)$$

where TP is the number of True Positive classified cases, FP is the number of False Positive classified cases, and FN is the number of False Negative classified cases.

Considering this is a multiclass problem, each class's metrics are calculated individually. Then, macro-averaged accuracy and recall are calculated as the average of all classes for each ML module. Since we have tested the inclusion of different numbers of parameters, macro-averaged metrics are calculated for each number of parameters.

V. RESULTS

In this section, the results of image processing and data classification are conducted. First, the results obtained after applying the GLI and the reclassification are described. Then, each grape's estimated quality is described. Finally, the classification results based on ML algorithms are discussed.

A. *Image processing*

The application of GLI allows, on the one hand, to reduce the image size by having a single band instead of three bands. On the other hand, the new band maximises the differences between the greener areas, the healthy grapes, and areas with other colours, such as bumps, damages or fungic infections.

The RGB and the index have been calculated for the RGB images captured during the experiments. Results can be seen in Figure 3. Next, the reclassified image according to the established thresholds in Table I is displayed with the circles indicating the segments to be analysed.

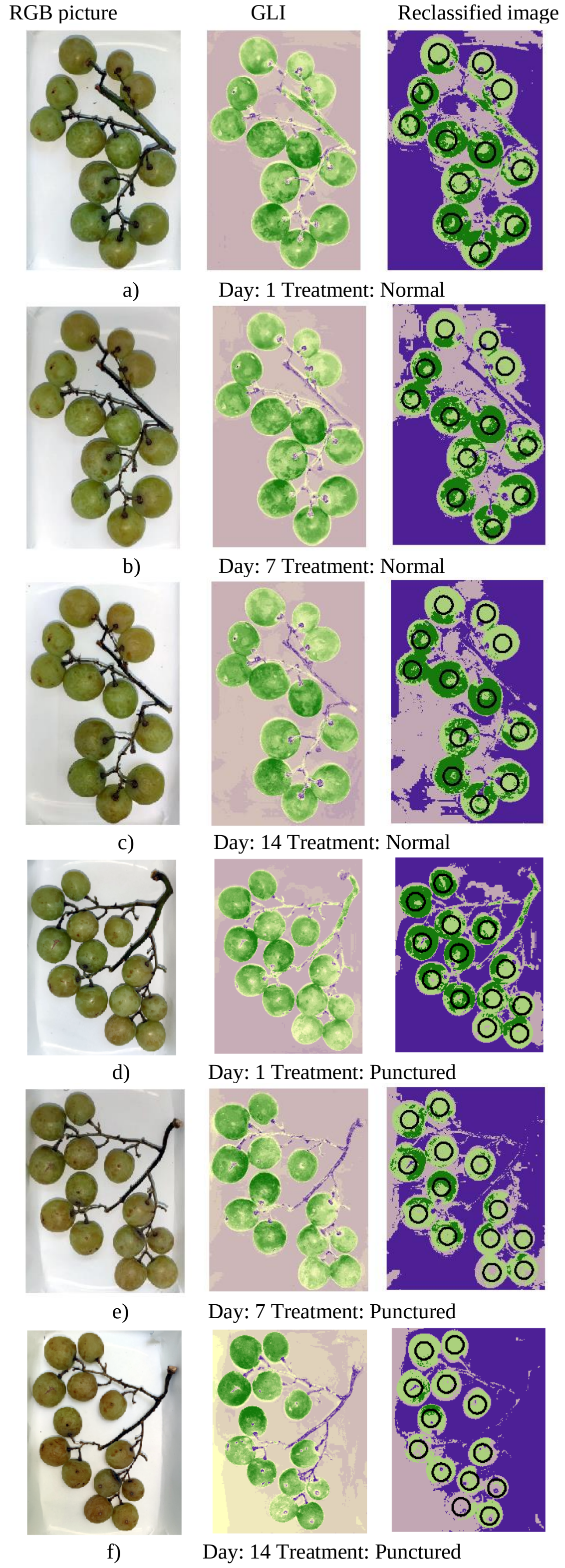

Figure 3. Process followed for image classification.

In Figure 3 a) and d), we can see the image of the first day with the standard treatment and punctured grapes. Figure 3 b) and e) correspond to the pictures after 7 days for the normal and the punctured treatment. Finally, Figure 3 c) and e) correspond to the images after 14 collections with the different treatments. It is possible to see that there are differences among the treatments and over time in the RGB image. Nonetheless, the differences are much more evident when the GLI is applied and when the image is reclassified.

Concerning the feature extraction results, an example of data of obtained histograms from a random grape of normal treatment and a random grape of standard treatment can be seen in Table 2. In the Table, it is possible to see the number of pixels contained in the studied segments for each one of the 4 classes.

TABLE II. EXAMPLE OF OBTAINED HISTOGRAMS

Class	Example of Grape of Normal Treatment			Example of Grape of Punctured Treatment		
	Day 1	*Day 7*	*Day 14*	*Day 1*	*Day 7*	*Day 14*
1	0	0	1092	0	6	889
2	0	0	203	0	136	314
3	355	27	1339	1020	6312	6441
4	27292	33739	43166	42276	42520	41382
5	21394	15280	3243	5727	63	13

B. *Classification results*

This subsection presents the results of different ML modules for solving the multiclass problem based on data obtained in the previous subsection. In Figure 4, the macro-accuracy results can be seen. Regardless of the number of included parameters, the KNN is the algorithm that offers a better performance in terms of accuracy, followed by ANN. When the KNN algorithm is used with 4 or more parameters, 100 % of accuracy is reached. No other algorithms achieve similar results. In the case of results with the ANN, the maximum accuracy is 95.2 % with both 4 and 5 parameters. The worst accuracies are obtained with BN with maximum accuracy of 78 %, SVM, and DA, the last two of which have similar performances.

Concerning the macro-averaged recall, the results can be seen in Figure 5. Again, the KNN algorithm's performance is the best among the tested ML methods. As for accuracy, 100 % of recall is achieved when 4 and 5 parameters are used. In the case of the ANN, the recall reaches 92 % when 4 or more parameters are used.

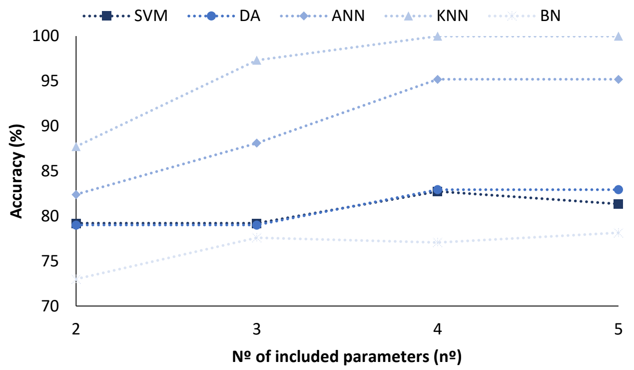

Figure 4. Macro-averaged accuracy results for the different tested algorithms and with different numbers of included parameters.

Contrary to what happened in the case of accuracy, the worst results are linked with SVM, with recall values below 40 % in all the cases. The performance of DA is slightly better than that of SVM, with a maximum recall of 46 %. Finally, BN is in the third position among the tested algorithms. It is the only one that has an increase in its performance when the last parameters are included, rising from 55 % with 4 parameters to 67 % with 5 parameters.

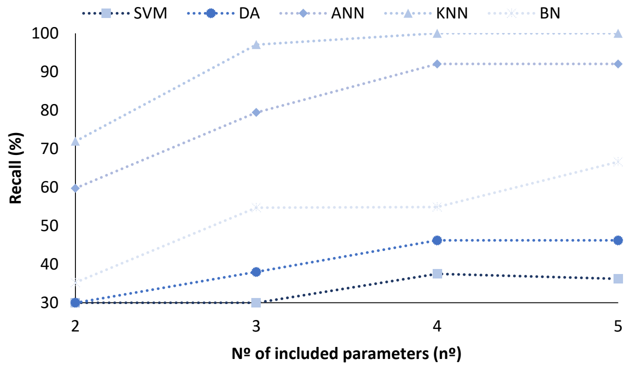

Figure 5. Macro-recall accuracy results for the different tested algorithms and with different numbers of included parameters.

After analysing the results, it is possible to affirm that in order to maximise the performance of the system, it is required to use the KNN algorithms as an ML tool to classify the data. It is recommended to use 4 parameters since the results when an additional parameter is included do not increase, and a lower number of parameters will have less space in the DB and less information to be exchanged with the cloud server, thus decreasing the network requirements and energy use.

We can affirm that the proposed methodology for fruit quality determination using image processing and ML tools offered promising results. Accuracy and recall equal to 100 % have been achieved. For the application of this system in real conditions, it will be recommended to include additional cameras to gather more images from the same bunch to avoid the overlapping effect.

C. *Limitations*

There is a series of constraints to be considered in this study before its implementation in real conditions. As mentioned in Section IV A, to avoid overlapping two or more grapes, they were carefully distributed to make it easier for the program to detect the area of the grapes. It remains to be determined in which sense this overlap affects the image generated. The program may detect one grape instead of two. Further studies should be carried out to study how to avoid this overlapping and how to solve it.

In this study, the camera used to obtain the images of the bunch of grapes was a conventional camera. For future studies, it would be advisable to use a higher resolution camera to better delimit the area of each grape.

VI. CONCLUSIONS AND FUTURE WORK

Rapid fruit quality evaluation is extremely important in warehouses along the value chain. While there are several proposals to control and reduce fruit quality decay, few methods are found to evaluate the fruit quality remotely during the storing and processing periods.

In this paper, we have proposed, analysed and verified a methodology to determine the fruit's quality and the fungi's presence based on image processing. The proposed method is based on applying GLI, image segmentation and using ML to classify extracted features. With KNN, accuracy and recall of 100 % are achieved even if not all the extracted features are included in the classification.

The future work will include adding additional sensors, such as gas sensors [20] with the aim of predicting the fruit's quality decay. In addition, the study of other grape varieties and other berries is foreseen to evaluate the suitability of this method with fruits characterised by other colours.

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An Application of Systems Thinking – Food Systems

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***Abstract* – Most of us make our weekly trip to the grocery store, purchase, and consume our favorite foods without giving much thought into where it came from, the resources used to get it from farm-to-plate, laws and regulations dictating food safety and sustainment, factors influencing price, political pressures, etc. Our modern day food system is one of the most complex systems in society and is facing many challenges that includes feeding a growing population, distribution, managing ecosystems, nutritional value, and water shortages to name a few. To get to the root of these issues, they need to be viewed from a system's point of view, tackled as systemic issues of the food system as a whole, instead of trying to solve these individually. This paper will apply the Systems Thinking framework to create an abstract model of the modern day food system that goes beyond food production, cultivation, distribution, processing, consumption, etc., but also dives into the socioeconomic factors, laws and regulations, environmental impacts, ethics, as well as external systemic impacts. Ultimately, the analysis done here will be used to lead the way into future research and system analysis that will lead to innovative ways to optimize the current food system and further build upon existing models and framework that may be used to help mitigate some of the major known impacts on the food supply.**

Keywords–Systemigram; Interest Map; Context Diagram; Drivers.

I INTRODUCTION

There are many challenges with our current food system, at varying degrees of severity and scale. Some of the major challenges with the food system include sustainment and the ability to feed a growing population with ever increasing strains on water supply, increase in poverty, a changing global environment, wars, political unrest, satisfying laws and regulations, reducing impacts on local ecosystems, and understanding the nutritional needs of the human population. An example of geopolitical pressures straining the food supply is the Russian-Ukraine war currently taking place, which is directly affecting the global supply of grain. Prior to the war, around 90% of Ukraine's agriculture exports were seaborne, but blockades due to the Russian conflict has brought these exports to a virtual standstill, leaving a devastating impact on Ukraine's economy and a significant spike to food prices worldwide [3]. Figure 1 below shows the worldwide impacts (food price index) due to geopolitical instability on the food supply relating to the Russian-Ukraine war. This increase in food price index further stresses an already recessed global economy. This forces nations to find other sources, which may have complications due to a variety of other factors.

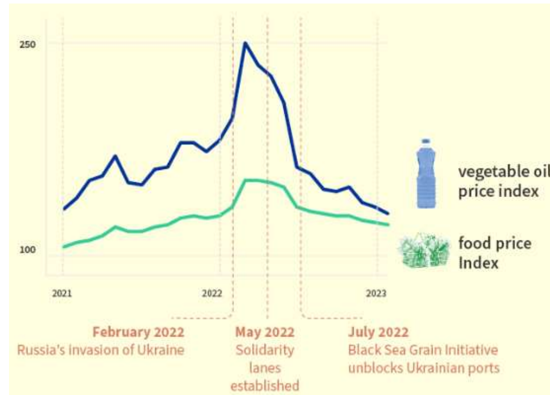

Figure 1. Food Price Index Impacts on Russian-Ukrainian War [3]

Another example is climate change, which is turning what were once fertile lands into dry basins creating the engineering challenge of finding other water sources or conserving existing supplies for crops (as shown in [9] and [10]). In order to dive deep into these issues, one needs to understand the complex relationships and shaping forces that make up the food system with its stakeholders. What interactions and interrelationships impact the food supply chain. How can we improve existing processes, and eliminate non-value added ones? To answer these, first we must answer the question "what is a Food System"?

The first step in understanding the problem that is our "Food System", a formal definition needs to be developed and agreed upon. According to Oxford University, The Food System is a "complex web of activities involving the production, processing, transport, and consumption. Issues concerning the food system include the governance and economics of food production, its sustainability, the degree to which we waste food, how food production affects the natural environment and the impact of food on individual and population health" [1]. By this definition, our food system is not only the processes and technology involved with cultivating, distributing, processing, and consuming food, but also the governance of food, the economics of food, sustainment of the food supply and the environment. All of these aspects are key drivers of the food system. As shown in Figure 2, there is a feedback loop, where the drivers impact the food system (i.e., environmental, and socioeconomic drivers directly impact food system stability and supply) and vice versa (producing more food means more people can be fed, decrease in available water supply to population, and more greenhouse gas emissions).

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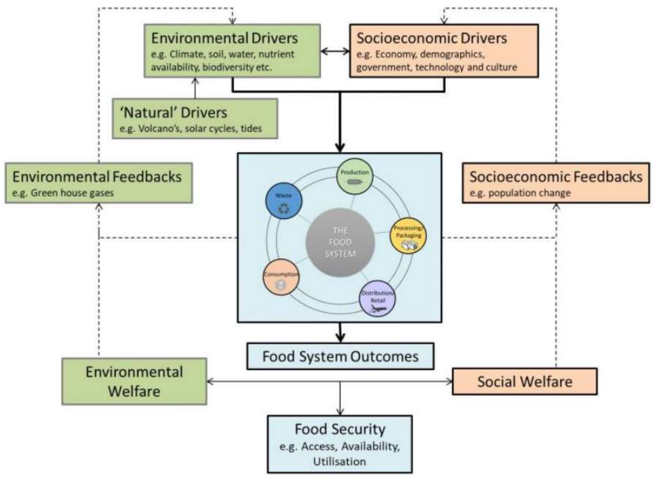

Figure 2. Food System Drivers [1]

As we begin our systems thinking approach to developing a holistic view of the food system as defined prior, this paper will dig deeper into each of these drivers, how they relate to our stakeholders, how they shape our system, what processes work, which ones have areas of improvement, and how we can use these drivers to sustain the food supply. This paper will not solve world hunger, but it will help establish the framework to better understand the knobs and levers that control some of the drivers responsible for world hunger along with other downstream effects to mitigate disturbances to the food supply.

In Section 2, a stakeholder perspective analysis will be performed to identify stakeholders, understand their interactions with the system and their values. In Section 3, value-added (and non-value-added) processing will be identified, as well as the shaping forces that dictate these factors. In Section 4, an analysis of shaping forces will be performed to better understand how external (and in some cases internal) drivers that impact or dictate the system's behavior and limitations. In Section 5, critical properties of the system will be analyzed and interpreted through the use of systemigrams. These types of diagrams help to build a framework of system interdependencies, tying in all stakeholder perspectives to tell a story.

II. STAKEHOLDER PERSPECTIVE ANALYSIS

Earlier, we defined what a food system was and talked briefly about the "drivers" of this system. From here, one can develop a list of considerations for this system of interest.

Table 1 is a list of (key) considerations for the food system per our definition. Some considerations worth noting include Environmental considerations, which not only has to do with the land's ability to yield large amounts of crops, but also the impacts that crops, livestock, factories, etc., have on the local ecosystem. Sustainability which ties into future generations. It is important to have a sustainable food supply for the foreseeable future. Socioeconomic factors like demographics and economy drive the types of food, the quality and scalability of the food sources. Technology allows for larger crop yields but may also have an environmental footprint. Finally, the stakeholders who have a direct stake in food systems, though technically the entire human population can be viewed as stakeholders of such a system, we can still divide this up into discernable categories as shown in the context diagram below in Figure 3.

TABLE I. SYSTEM CONSIDERATIONS

Food System Considerations	
Considerations	**Description**
Environmental	Includes anything from fertility and climate to availability of water supply, environmental welfare, and impacts on local ecosystems
Sustainability	Long term sustainment of resources, land, food supply, trade routes, etc.
Supply and Demand	Ensure a steady supply to meet demand
Costs	Costs due to production, distribution, governing, etc.
Mass Production	Mass production system that is sensitive to demand, ethical, minimal downtime and disturbances, etc.
Distribution	Distribution from trade amongst countries to grocery store deliveries down to the customer
Efficiency	Producing and distributing food costs resources, making efficient use of these resources vital to keep costs reasonable, remain sustainable, keep a steady supply, etc.
Stakeholders	See Figure 3 Context Diagram
Safety and Governance	FDA, world trade laws, etc.
Future Generations	Availability of food supplies in the future
Economy	State of economy impacts food availability
Demographics	Cater food supply to regional demographics
Technology	Technology available in support of food production and distribution

In the context diagram, the Food System boundary is established by the larger lighter shaded yellow circle. The darker yellow circles inside make up some of the key subsystems of the overall food system. The blue squares are the stakeholders where their relationship or connection to the subsystem is established by the arrows pointing to the food system. The green boxes show some of the external systems that directly/indirectly interact with the food system. Though technically the entire human population would be considered a stakeholder, the ones shown here in blue represent a layer of abstraction down from that. These stakeholders can be further extracted, for example "Food Related Appliance/Product Manufacturers" can be broken down into farm equipment, trucks for distribution, and even ovens, air fryers, toasters, etc., for the consumer markets.

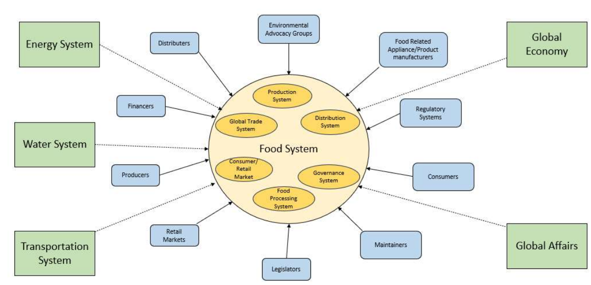

Figure 3. Food System Context Diagram

An interest map (as was done in [7]) can be seen below in Figure 4 that gives a more dynamic depiction between the food system and its stakeholders.

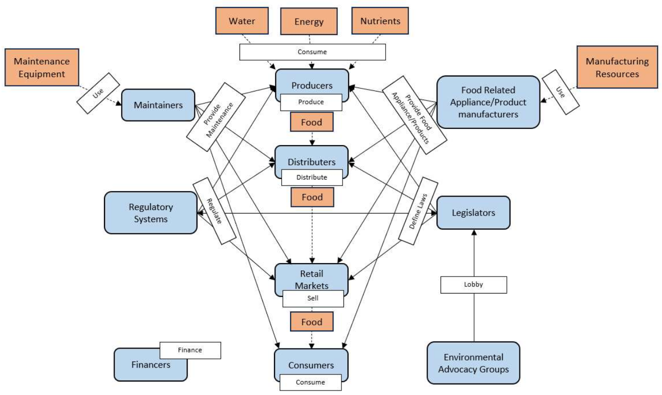

Figure 4. Interest Map Food System

From the interest map shown above, one can get an idea of how the various stakeholders (blue boxes) take part in the food system. We see some stakeholders taking in external objects shown in orange (i.e., producers taking in water, energy, and nutrients). Interactions between such objects and a stakeholder are represented by a dashed arrow. Actions are shown by the white boxes (i.e., legislators define laws, retail markets sell food, etc.), and the straight arrows show the connections between stakeholders and their subsequent actions. Some relationships are two-way (indicated by a two-way arrow) such is the case between legislators and the regulatory systems. This relationship, though abstract, is important because we get a bird's eye view of how a change in one aspect of the system (i.e., regulatory system) can impact various other aspects of the system (i.e., producers, distributors, retail markets, etc.).

III. VALUE-ADDING PROCESSES ANALYSIS

Now that we have established the key stakeholders, defined the system context and dynamic interactions among stakeholders and the system, next we can answer questions like "What is the system trying to achieve?" or "What is it's true value?". How can this system's value be defined in its own terms and connection with other systems it interacts with? What processes are enabling the system's achievement?

In order to answer these questions, it is crucial to start looking at things from the stakeholder's point of view. From the point of view of our producers, the goal is to provide food and generate revenue. It is important for both the producers and governing bodies that food is produced in a manner than meets regulations. It is important for environmental advocates to produce food in an environmentally conscious way. Financers want returns on investments, and distributors want a means of distributing goods and generate revenue. All of these get into the topic of "What do our stakeholders find valuable about food systems"? Table 2 below is a list of stakeholders and their corresponding values or expectations for a food system (as was done in [8]). Note a consistent theme among all the stakeholders (Have Food to Consume), which is necessary for survival.

TABLE II. STAKEHOLDER FOOD SYSTEM VALUES

Stakeholder Food System Values	
Stakeholders	**Food System Values**
Environmental Advocacy Groups	Highly Sustainable System Minimal Disturbance to Local Environment Abides by all environmental protection laws and regulatory guidance Ability to adapt to future energy trends Have Food to Consume
Producers	Provide Food Maximize Profits Meet Demands/Needs Feed population Have Food to Consume
Financers	Low Risk Food System Related Projects Completed Within Cost and Schedule Returns plus interest Have Food to Consume
Distributers	Resources Necessary to distribute goods Follow laws and regulations Provides goods in a timely manner Maximize Revenue Have Food to Consume
Retail Markets	Provide Food to Local Customers Maximize Profits Maintain customer satisfaction Accessibility to Food Have Food to Consume
Legislators	All Food Subsystems Satisfy Regulatory requirements and laws (global, national, and local) Have Food to Consume
Maintainers	Ease of Maintenance of Food Systems Maximize Profits Availability of Maintenance equipment, tools, and materials Have Food to Consume
Consumers	Easy Access to Food Low Cost Nutritional Value Variety Freshness Maintainibility and Supportability of Food Related Appliances and Equipment Safe Sustainable Source of Food for Future Generations Have Food to Consume
Regulatory Systems	Food System satisfies all regulatory requirements Have Food to Consume
Food Related Appliance/Product Manufacturers	Customers/market for food producers and consumers Maximize Profits Sustainable Have Food to Consume

With an understanding of system values, value-added processes can be established. A value-added process, in the context of this paper, is defined as a process of the food system that a particular stakeholder finds valuable. Below is a list of value-adding processes in relation to stakeholder values (The value of this system in its own terms). This list is not all inclusive provided the scale and scope of this system.

1. Growing/Harvesting Crops and Livestock (Farming Process)
2. Trading Crops and Livestock with Other Parties of Interest (Global and Local Trading)
3. Distributing Food to Retail Markets for Consumers
4. Retail Markets selling food and food related products (i.e., Ovens, Toaster, Mixer, etc.)
5. Regulators routinely inspecting food at various points along the supply chain
6. Food Preparation and Processing
7. Rotating Crops (sustainment)
8. Abiding by food related handling Laws
9. Water Irrigation Systems

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10. Food Production Equipment Maintenance and Customer Support

Next, we can define the value of this system in terms of the external systems it interacts with. From our Concept Diagram, some of the external systems of interest include:

1. Energy System
    a. Energy is needed to support the food system in terms of producing, distributing, regulating, selling, and consuming it
    b. Maximizes profits for energy producers
    c. Using energy efficiently and minimizing carbon footprints satisfies stakeholders like regulators, environment advocacy groups, etc.
    d. Provides jobs for those working in the energy system
2. Water System
    a. Crops, livestock, etc., require water
    b. Maximize Profits
    c. Using water efficiently and minimizing waste satisfies stakeholders like regulators, environment advocacy groups, etc.
    d. Provides jobs for those working in the water system.
3. Transportation System/Sector
    a. Transportation is vital to trading and distributing food and food related products
    b. Maximizes profits for trucking, shipping, and rail industries
    c. Provides jobs to those working in the Transportation System
4. Global Economy
    a. Maintaining low food prices reduces food price index, which has a positive effect on global economy.
    b. Lower food prices allow for better quality food to get to impoverished nations.
5. Global Affairs
    a. Trade is what binds nations together
    b. Food variety across nations

Now that the value of food systems has been discussed, it is time to begin thinking about some of the missing value-adding processes from the existing food system. This will also be an opportunity to dive deeper into some of the driver, or "Shaping Forces" of the food system in order to better understand food system influences.

IV. ANALYSIS OF SHAPING FORCES

In this section, an analysis of the shaping forces will be done to get a better understanding of the drivers that impact the system that both shape and dictate some of the system's general behavior and limitations (as was done in [6]). With this understanding, we can begin to understand how outside (or even internal) influences cause the system to behave the way it does.

In [2], the authors introduce the food system and sector frameworks and then consolidate this into an integrated framework that allows for rapid assessments of impacts on the food system. In this sense, the food system framework is "an application of systems thinking that links the production, processing, distribution, preparation, and consumption of food, with elements of the environment, people, inputs, infrastructure, and institutions. It describes the connections and feedback loops between those elements and processes.." [2]. The sector framework, in the context of the agriculture sectors, defines a set of activities (8 total) and attributes within the agricultural sector that are influenced by socio-economic and environmental drivers [2]. Activities as they relate to the agricultural sector include Production, Value Chain Development, Service Provision, Consumption, Stakeholder Organization, Regulation, Coordination, and Investment [2]. This integrated framework can be conceptualized in Figure 5 .

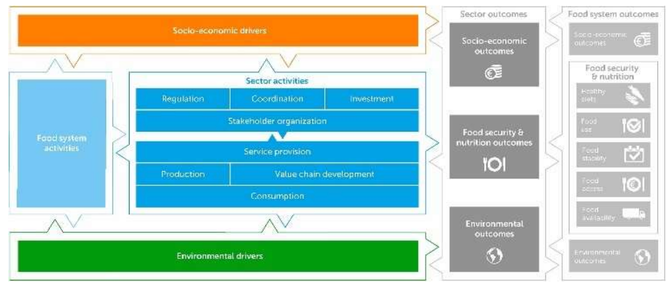

Figure 5. Integrated Food System Framework [2]

Through this integrated framework, there is a feedback loop between the drivers and the food system. The drivers drive the kind of food, the quality of food, the availability of food, and the price of food, food security, etc. The food system itself impacts these drivers by contributing to greenhouse gas emissions, dictating what needs the market has in terms of technology and food quality. Leveraging this integrated framework, we can defined the Shaping Forces of the Food System as:

1. State of Global Economy
2. State of Global Climate
3. Human Population
4. Latest Nutritional Guidelines
5. Food Market
6. Geopolitical Environment (wars, unrest, etc.)
7. Cultures
8. Technology (farming technology, appliance technology, distribution technology, etc.)
9. Availability of Resources
10. Water Source
11. Energy Sources
12. Local Environments

We can also determine some of the missing value-adding processes by analyzing this framework:

1. Integrate agricultural efforts with the existing landscape, as opposed to reshaping the landscape. [4]
2. Implement cultivation techniques that minimally disturb or impacts fertile soil
3. Raising livestock in a more ethical manner (grass fed, free roam, etc.)
4. Utilize green energy where applicable

5. Purchase and consume from local food markets, which cuts costs and energy use due to distribution, removing the “middleman”
6. Re-establish nutritional guidelines more frequently so that they are up to date with latest research
7. Incentivize locally produced food via tax incentive programs
8. Create programs that allow for selling/giving away unused food (reduce food waste)

V. SYSTEMIGRAM ANALYSIS

Finally, in order to present a proper definition and holistic view of the food system that can be agreed upon by all stakeholders, a Systemigram Analysis was performed (as described in [5]). Systemigrams are a system thinking tool used to provide an “inertial frame of reference” of sorts from the perspective of all stakeholders for the system of interest. It can be used to describe the interconnections in a “storyboard” like context. The systemigram for the food system is shown in Figure 6. The system of interest is shown at the top left (Food System) with the end node (bottom right) representing what the food system needs to accomplish in a way that satisfies all stakeholders.

The overarching mainstay of the food system is to produce, distribute, and provide food to meet food demands. The food system contains a consumer market that purchases goods through retail markets to provide products (food and food products) in order to meet demand. The food system also consists of a transportation and distribution system that distributes food for retail markets and consumers. The food production system provides food for distribution. Both food production and distribution systems are regulated by all levels of regulators, which themselves are funded by financers (private, public, and individual). You can also see that food demand has impacts on the environment, availability for future generations, and supply in the market, which dictates prices. The systemigram tells a story about not only the hard systems, but their interactions with the soft systems which is often overlooked.

VI. CONCLUSION AND FUTURE WORK

The modern day food system is one of the most complex systems in human society. Because of its complexity and delicate balance, the food system is at constant risk of disruption, which can have devastating impacts worldwide. A conflict on one side of the world can impact food prices on the other side. A changing climate could strain the supply of a particular food product, forcing the human population to adapt to an alternative food product. Growing populations stress the food system, requires more water and energy, thus impacting an already stressed water supply and contributing to greenhouse gas emissions. A system so vital to human survival requires care, and understanding of all of the forces that shape it.

In this paper, we applied a systems thinking approach to the food system. We defined the system not only in terms of its hard/physical systemic properties, but it’s “soft” properties (social, economic, political, etc.). We established a system context, and stakeholder value list that allows us to better understand the true value of the food system from all perspectives. Understanding the value of this system allows us to eliminate processes we find do not add value, while also allowing us to come up with ways to improve existing processes further. This requires understanding all of the key drivers that shape the system into what it is. We tied all of these together into a storyboard like structure known as a systemigram, which provides us with an agreed upon, inertial frame of reference for the system of interest.

Some of the challenges involved with characterizing such a system had to do primarily with the high complexity and large scope of the Food System. Though the Systems Thinking framework is designed to work with such complexity, understanding the interactions and defining the context such that the system was not boundless due to the scope was a challenge. Further analysis will need to be performed to clear some of the lines of the system boundary. The systemigram also required several iterations before an agreed upon definition of high level system interactions can be established. Future work will involve many more

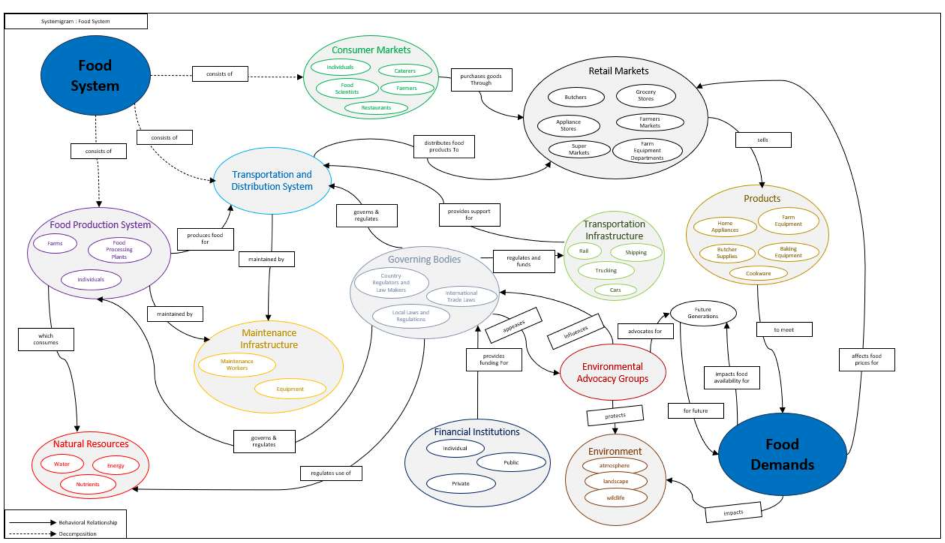

Figure 6. Systemigram of Food System

iterations of the systemigram, and even a breakdown of lower level systemigrams to define some of the lower level interactions of the food system from the perspective of specific stakeholders. From there, we can begin to tackle some of the major issues mentioned earlier in this paper such as sustainment of the food supply for future generations, reducing the environmental impacts of food production, and continue to feed an ever growing population even in the face of major global conflict.

Food is not only critical to survival, but also a business, a hobby, and people's livelihood. Food brings together cultures, binds nations while also causing conflict for others. Our food system is a delicate balance that has both strengthened and threatened our existence since the beginning of time. Understanding such a complex system can only be achieved through the use of systems thinking.

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