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Multidimensional Engineering Design Education for Modern Applications: A
Smart Grid Design Case Study

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1. Introduction

The design of new services and products based on technological advancements is one of the greatest challenges in engineering. This process has been traditional performed considering reduced realities of complex system using selected economic and technological parameters designated based on a generic group of customers [1]-[2]. Still, the massive digitalization of our modern society has significantly increased access to customers' data, allowing for the effective identification of the diverse groups consuming a respective service or product. As well as their respective needs and expectations regarding that service or product, which can sometimes be disregarded due to the lack of customization in the design process [3].

In this sense, modern solutions must be designed in ways to enable equitable access to the diverse groups they serve, i.e., all customers' groups must have their needs reasonably considered during the design process; a feature that is not achievable considering traditional technical-based design solutions disregarding the holistic nature of modern engineering systems [4]-[5]. For this, engineering design education must be expanded in ways to recognize and incorporate the multidimensional aspects involved in the customer-product/service relationship into the technical design scope.

In this perspective, this paper seeks develop a new methodology for engineering design education that ensures technically sound designs able to incorporate multidimensional perspectives required for ensuring an effective customization of services for a broad spectrum of customers groups. For this, a design approach respectively focused on macro- and local-thematic is developed. This approach capitalizes on advancements in philosophy of technology with a special focus on holistic principles to motivate critical thinking regarding both macro- and local-thematic during engineering design education. For this, besides strong theoretical analysis on macro-thematic factors regarding technological perspectives, such as architectures and infrastructures required for the respective engineering application design. Local-thematic factors based on social, economic and regional aspects are also explored toward the achievement of a multidimensional design able to model and meet the needs of different customers' group characteristics. For this, information and communication technologies (ICT) paradigms on data identification, services sharing, and the integration of technologies can be explored, including advanced metering, data-intensive computing (Big Data) and internet of things (IoT), e.g., [6]. Based on this methodology, a multidimensional design process for modern engineering applications is presented, enabling an effective harnessing of technological advancements toward actual needs and expectations of diverse customers' group.

To verify the proposed methodology, a case-study depicting the electric power grid modernization journey toward Smart Grids is presented. Smart grids represent electric power grids evolution into more sustainable systems with high integration between customer-utility [7]. Based on the proposed holistic engineering design process, a successful modernization journey can be designed featuring strong common theoretical backbones, while enabling customizations based on the particular needs of the diverse customers' groups served, e.g., Smart Grid projects for high-income neighborhoods are likely to be focused on service reliability, whereas for lower-income neighborhoods Smart Grid projects can be focused on tariff reduction.

2. Multidimensional Design Based on Philosophy of Technology Holistic Principles

The increasing awareness of engineering solutions footprint and impact in social and environment aspects, e.g., humanly developed structures currently exceed earth biomass [8]-[9], have motivated the development of novel in-depth analysis seeking to overcome the traditional belief that engineering solutions are exclusively focused on the technical aspects.

These new analyses present a holistic view of engineering problems including impact and influence from humanistic, social and philosophical aspects, culminating in thorough, robust, and intelligent solutions that can adequately identify and address the morality and ethics of technological design and engineering role [10].

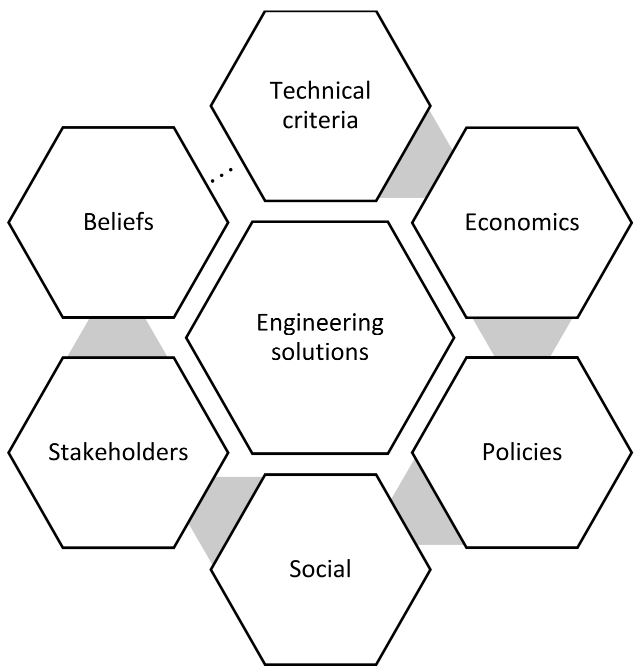

Fig. 1: Multidimensional aspects within modern engineering solutions design process

In this perspective, holistic engineering and technology design seeks to provide solutions that consider all stakeholders' interests while harmonizing multiple technical, human, and environmental aspects, [11]. For this, while recognizing that one must focus on key aspects, components and/or systems when designing engineering and technology systems and products, as it is not possible to take into account the full complexity of these systems given the complex relationships of its multiple realities. One can still be capable of outlining critical aspects, respectively fifteen irreducibly distinct and fundamental kinds of meaningfulness [12], that provide a useful perspective to ensure a comprehensive engineering design capable of accounting multiple aspects beyond "technical adequacy". In this process, system modeling characteristics are divided in aspects ("key characteristics"), core values ("modalities of meaning") and standards ("law spheres") illustrated in Table 1, [10].

Table 1: Engineering designing aspects, core values and standards

Aspect	***Core value***	***Standard***
Quantitative	Amount: number and quantity	Arithmetic laws
Spatial	Extent: space	Spatial laws
Kinematic	Movement: change in space	Dynamic laws
Physical	Force, energy, matter	Physical-chemical laws
Biotic	Life: organic and vital	Biological laws
Psychic	Sensorial, sensations, mind	Psychic laws
Analytical	Logical, rational, precise	Logical norms
Formative	Shaping, power, domain	Formative and/or technological norms
Lingual	Symbolic meaning	Symbolic norms
Social	Interactions, community	Social and institutional norms
Economic	Stewardship, resources, productivity	Economic norms
Aesthetic	Harmony and beauty	Aesthetic norms
Juridical	Justice and law	Juridical norms
Ethical	Love, care, service	Moral norms
Faith	Vision, creed, religion	Faith norms

Following, advancements in philosophy of technology, [11],[13], expanded the original perspective into holistic design methods toward modern engineering applications, Fig. 2. Holistic design seeks to provide justice to the multiple aspects, or dimensions, within a system, in the sense of not identifying just aspects or dimensions, but rather on the achievement of justice to laws and norms.

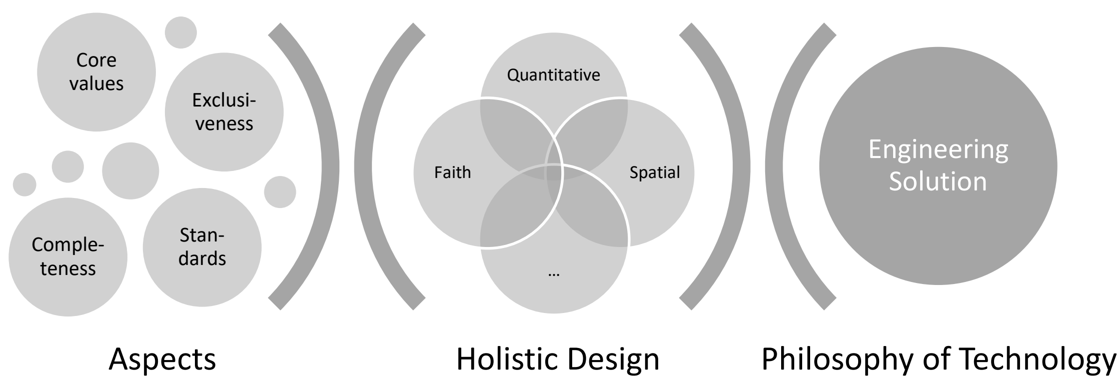

Fig. 2: Engineering solutions design philosophy of technology

For this, each aspect must respect the following properties:

<u>(1) Core values:</u> Aspects have unique core values: e.g., the core values of the physical aspect are different from the moral aspect, and so on.

<u>(2) Exclusiveness:</u> Aspects cannot be reduced to other aspects: e.g., the biological aspect cannot be reduced to the physical aspect, and so on.

<u>(3) Completeness:</u> Every system function in all fifteen aspects: i.e., system's design must be developed considering all aspects.

<u>(4) Standards</u>: Each aspect has its own standards, i.e., specific "rules and regulations" are presented for each aspect.

In this perspective, this work seeks to harness this structured holistic design method to overcome traditional engineering design education, that typically limits its analysis to the study of key technical perspectives on the macro-thematic level, disregarding interactions between the respective subsystems modeling these key aspects, and the multiple influences due to local-thematic in the design and decision-making process [14]. Moreover, the proposed holistic engineering design education prevailing over the restricted use of key technical macro-thematic factors, allow for the design of equitable and inclusive solutions through the consideration of the diverse influences associated with the project. This is an especially critical feature given that key technical macro-thematic factors used for traditional engineering design may be developed based on specific group(s) of our society. Therefore, not accounting for the uniqueness and diversity that local-thematic may impose, and even demand, from the respective solution, e.g., Smart Grid projects for a high- and low- income regions significantly differ on its design features due to local-thematic.

3. Case Study: Smart Grid Design

To illustrate the proposed multidimensional design process for modern engineering applications based on philosophy of technology holistic principles, a case-study depicting the electric power grid modernization journey toward Smart Grids is presented [4], [15]. The developed analysis contrasts Smart Grids solutions with traditional electric grid aspects, delivering a descriptive perspective of the impact that holistic design can provide to modern engineering solutions design, Table 2 [15].

The obtained results acknowledge that engineering infrastructures are extremely complex design problems, yet showcase that through a methodic approach using the four core properties for aspects definition, respectively: (1) unique core values; (2) exclusiveness; (3) completeness;

and (4) standards. These systems' complexity can be broken down into multiple distinct aspects tackled through macro- and local-thematic realities toward an effective holistic design solution. Resulting in technically sound designs able to account for equity, diversity and inclusiveness through macro- and local-thematic considerations.

Table 2: Holistic design application for Smart Grids

Aspect	***Traditional Power Grid***	***Smart Grid***	***Standard***
Quantitative	Numbers	Measurable quantities: system parameters, equipment, etc	Arithmetic laws
Spatial	Use of space	Storage, Generation, transmission and distribution systems	Spatial laws
Kinematic	Dynamic components	Moving components, e.g., generators, power flow, etc.	Dynamic laws
Physical	Materials and properties	Generators, transformers, cables	Physical-chemical laws
Biotic	Effects on animals, humans, environment	Electromagnetic fields, waves, electric shock	Biological laws
Psychic	Feelings, e.g., safety or fear	Probability of blackouts, electric shock, etc	Psychic laws
Analytical	Diagrams, models, analysis	System modeling, problems solutions, etc.	Logical norms
Formative	Control	Control of power generation, transmission and distribution	Formative and/or technological norms
Lingual	Terminology	Symbols, definition of 'smart', etc.	Symbolic norms
Social	Influence on society	Human behavior	Social and institutional norms
Economic	Cost of energy	Price differentiation, incentives, etc.	Economic norms

Aesthetic	Infrastructure construction and organization	Harmonic with the environment and between components	Aesthetic norms
Juridical	Liability, ownership	Insurance, stakeholders,	Juridical norms
Ethical	Social and environmental responsibilities	Foundations, spaces, events focused on social and environmental actions	Moral norms
Faith	Trust in the system	Vision, commitment, belief on a smarter system	Faith norms

4. Conclusion

Engineering solutions are typically complex systems that require the consideration of several aspects during the design stage. Simultaneously, engineering design education has been traditionally focused on selected key aspects usually restricted to the technical macro-thematic. In this sense, this work seeks to overcome this perspective, providing a multidimensional design process for modern engineering applications. The proposed approach takes advantage of philosophy of technology holistic principles to motivate critical thinking about both macro- and local-thematic during engineering design education, providing a checklist of aspects to be considered and fulfilled during the design process. Based on this methodology, a holistic engineering design process is achieved, enabling an effective harnessing of technological advancements toward actual needs and expectations of diverse customers' group through equitable and inclusive solutions.

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