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Exploring Perspectives on Engineering: Trajectories and Narratives

Yusuf Syed[1]

[1]Collège du Leman, Switzerland

ABSTRACT

Engineering, a subject of empirical rigour with the axis of performing a practical function for a system or device user, continuously translates knowledge into social change through an ever-changing modern lens, retaining a dual resonance in the frame of professional evolution. Firstly, a progression of available conceptual knowledge and approaches will occur. This induces the change observed in professional structure and alteration in engineering role and character. These outcomes may be discussed through the path of the discipline's professional trajectory in parallel with an engineer's archetypal portrait, not with reference to scientific knowledge expansion, which is characteristic of different historical periods, but in terms of the development of engineering approaches. Although it is often overlooked, at the core of true engineering is a philanthropic heart and the desire to deliver a productive service. Thus, the second evolutionary force is effectively social and forward-looking in nature as public needs grow and diverge, addressed through innovation's social role. The convergence of these two elementary dynamisms of conceptual and social roots, is exemplified in a case study on Kisiizi Hospital, which speaks directly to the aim of this study: to achieve a comprehensive view of the modern engineering mentality's application in social settings.

Propelled by interviews with engineers and project managers alongside primary studies, this exploration proposes the invariance of core engineering frameworks whilst technical progression is observed. This constitutes agreement with the understanding of a professional system of profiles which acts as the stem for social, economic, and technological advancements.

Introduction: A Qualitative Approach to a Quantitative Subject

Perhaps the defining factor of engineering and its branch of work is its practicality. Innovation is data-driven and innovation drives data collection, forming a cycle of inherent reliance on quantitative analysis. Inevitably, qualitative feedback is received on device performance and the user interface from the uninformed operator, however, satisfaction is still quantified and categorized to suit the engineering approach. This publicized dimension of empirical engineering relates to the progression of knowledge. The element of moral inclination to deliver a helpful service is much more difficult to express quantitatively, although it may be supported in this way. Thus, semi-structured interviews were used alongside primary studies to achieve a holistic view of engineering interventions not solely for technical appreciation, but to better understand the analytical and devoted mind.

The primary studies and literature used concerns engineering approaches and outcomes as opposed to the body of knowledge which have enabled these to occur. Similarly, the semi-structured interviews revolve around individual experiences, contributions, and perspectives, so as to reflect the evolution of the discipline's role and not its content. Guiding questions were proposed in order to direct the interview towards the topics of primary interest, whilst allowing space for individual-specific exploration.

The assimilation of this knowledge towards a tangible synthesis requires situational analysis of an experience. This consists of identifying an issue, mapping the solution, and executing the intervention through a contemplated innovation framework. These criteria are fulfilled by the rural Ugandan hospital case study, where a power deficiency

inhibited provision of quality healthcare services. Using abundant natural water resources, hydroelectric power was proposed as the solution and an expansive mediation was accomplished via a technical and solution-oriented approach. A fundamental exemplar of reverse innovation opportunity, this engineering intervention demonstrates the compatibility of all project frameworks in terms of core approaches and perspectives whilst also highlighting the need for sufficient practical knowledge.

[1] Evolution of Professional Trajectories

As public demands for diverse products and services grow exponentially, the role of an engineer has transcended beyond device design and innovation. Instead, the discipline's contributions have filled needs in all industries. Engineering is the silent language spoken in every analysis-based discussion, report or examination. The essential application of knowledge to improve, design or reconstruct a system, is, inherently, a form of engineering, however, the diversification of the field has resulted in a widened scope for critique and devaluation of its perspectives. Due to the rapid ascension of the technological age, multiplying populations of various demographics now dismantle engineering's appellation in social evolution, with its contributions taken for granted. From commercial applications of its approaches to aerospace research at NASA, rapid change has deducted from the appreciation of change itself. Society has become increasingly reliant on engineering and technology, whilst becoming increasingly apprehensive of its potential. Consequently, professional evolution must be approached cautiously from a triad of angles.

(1) Explicit engineering may be expressed as the classical form of the profession, implementing a tangible design or product to solve a visible issue or satisfy a need. This directly involves the application of a concrete set of scientific knowledge to yield a prominent resolution. Discussing her professional trajectory, an environmental engineer outlined her inclination to contribute towards rectifying palpable social welfare deficiencies through the pursuit of ecologically beneficial water and sanitation reform. Notably, work in East Africa to uphold secondary school education, water supply projects, and designing wetlands to treat wastewater, provides a lucid example of explicit engineering's reliance on cultural and social awareness. In this context, engineering acts as an instrument to remedy a social dilemma, induced by an identifiable incapacity for a productive lifestyle to be optimally pursued. Explicit engineering, therefore, is relatively invariant in terms of innovation framework. Its evolution is solely dependent on how public needs and scientific knowledge changes chronologically. Contrariwise, its invariant innovative template can be summarized in the following structure:

a. Define ultimate objective and criteria for success, accounting for project constraints and functional priorities.
b. Evaluate current situation and compare against proposed outcome to assess practicality, feasibility, and desirability of intervention.
c. Consider the magnitude of risks to avoid circles of casualty.
d. Gage social integration success to analyze coordination possibilities with related systems.

This professional framework is rewritten and followed in different contexts in terms of the scientific context and public demands. Hence, explicit engineering, evolves over time dependent on two factors: scientific knowledge and social desires.

(2) Implicit engineering is present in social infrastructure and diverges from device construction towards system construction. This distinction essentially means that implicit engineering does not culminate in a product but enhances the optimum capacity of some user interface. In the example of product technology and management in the commercial industry, a project manager for investment with an initial grounding in electrical engineering, discussed the role of engineering training and analysis to promote new market growth and nationally translate innovation templates, inducing industry expansion. In many ways, a hierarchal connection between implicit and explicit engineering can be established. Implicitly using core skills of critical reasoning, situational analysis and problem-solving, whilst

employing a solution-oriented approach to drive forward market globalization, enables, for instance, product adaptation to social contexts, a form of explicit engineering. Outlining the role of cost-analysis in product development, a vivid description of engineering training as a method of "acquiring a toolbox for universal application" was distinguishable. Professions incorporating implicit engineering partially act as primers for explicit engineering, whilst being dependent primarily on public needs as opposed to both social and scientific factors. Despite their fractional discrepancy in frames of knowledge or contexts, both forms apply identical frameworks for developing solutions to complex problems.

(3) Social view of engineering is the final factor to which professional evolution may be attributed. Thomas P. Hughes (1991) in his study *From Deterministic Dynamos to Seamless-Web Systems* defined the dependence of technological determinism on social dynamic[1]. Technological determinism is the overarching consensus that changes in available technology are the primary propeller of social evolution. This technology is not exclusive to digital devices as is commonly misunderstood. Instead, it refers to the network of systems and mechanisms that enable constructive lifestyles. The evolution of the wheel is a prime example of this, from a fundamental wooden carving capable of rotation to a now complex system of multiple modules, appreciated as an assimilation of material, mechanical and electrical engineering. Its role in transportation, has promoted globalization, exchange of cultures and, by consequence, an ignition of social norm and value reform. As technology becomes more intricate, public perception of it becomes less informed, effectively creating a communication deficit between the engineering profession and society. As this process materializes, engineering becomes less and less overtly present in decisions, despite playing a crucial role in them. This is the fundamental change implied when devaluation of public perception of the profession is discussed. Thus, whilst the profession expands, as in the cases of implicit and explicit engineering, social view of it constricts.

Comprehensively, the components of professional evolution illustrate the multiple dimensions of the change which occurs. Fig-1 forms the matrix of evolution propellants.

Fig-1: Engineering Professional Evolution Matrix

Component of profession evolution Propelling change force	Explicit Engineering	Implicit Engineering	Non-Technological Deterministic Social View on Engineering	Technological Deterministic Social View on Engineering
Scientific knowledge	x			x
Public needs/perceptions	x	x	x	

Approached from different perspectives, the evolution of the profession can be driven by varying factors. Overall, however, the same forces recur. Within the four components, omitting weighting, the primitive conclusion can be made that public needs are more prominent over professional evolution; however, this narrowed perspective is not representative of the entire subject. Furthermore, subjective assessments have been employed, diverging from the primarily positivist and objective nature of engineering. Therefore, this matrix lacks a considerable degree of quantitative validity, whilst still maintaining relevant for a holistic surface view of professional evolution.

[1] Thomas P. Hughes, "From Deterministic Dynamos to Seamless-Web Systems", *Engineering As A Social Enterprise,* (July, 1991): 7-13. https://doi.org/10.17226/1829.

[2] The Portrait of an Engineer

Typically considered the pinnacle of pragmatism and efficiency, the engineer is no exception to a contemplated and deliberate equilibrium of diverse qualities with enable a holistic approach to applied knowledge. As discussed, invariant core frameworks are present in the profession, however, these require a set of idealistic skills to uphold and implement. The portrait of an engineer may be discussed through the assortment and composition of this skillset which optimizes productivity and the turnover ratio of feasible, practical, and desirable output to net input.

Within the boundaries of this vague definition proposed, is an engineer's ability to identify circles of causality. The comprehensive outlook of system functioning through the iterative processes of deconstructionism and reconstructionism is enabled by an engineer's modular systems approach, as delineated by Madhavan (2015) in *Think Like an Engineer*. This methodical orientation of tackling system failure at the component level to refine the interactions of modules treats a system as a harmonious compilation of equally valued constituents[2], effectively enabling a balance of inputs to produce a practical output.

Weaved into this approach, which is integral to an engineer's qualities, is the understanding of how to coordinate innovation at each hierarchal system level, whilst remaining profoundly in touch with the goals of a desirable, feasible and practical outcome. In this instance, an engineer must be resistant to the Einstellung phenomenon, which proposes a cognitive bias, whereby the development of alternative solutions is inhibited by the fixation upon familiar and favoured knowledge within a tested frame of reference[3]. Fundamentally, these bias functions both as a barrier to innovation in parallel with a protector of system security and user safety. The archetypal engineer must, therefore, appreciate the Einstellung limitation, whilst be willing, driven and technically proficient to remove themselves from it.

In order to achieve this state of objectivity which epitomises the portrait of an engineer, the commercial project manager highlighted the need for persistence to accompany pragmatism. The infinitely expanding objective of "building a better world", necessitates the implementation of the tenacious determination mindset to iteratively design, test and refine systems within diverse contexts. Inevitably, contemporary feats of engineering may be catalysed by the individual, however, projects are now of a magnitude or intricacy which requires interdisciplinary collaboration. In a simple example, it is feasible for a mechanical engineer to understand how to construct a household desk chair to effectively distribute loads, yet to enhance the quality of device, a material engineer would likely need to analyse the distribution of tensile, compressive and shear stress within the frame to prevent structural failure.

Constricting the scope of this evaluation towards the academic qualities pertaining to an engineer's portrait, a software engineer working in precision medicine suggests the inquisitiveness and curiosity towards understanding our surroundings act as the fuel for professional growth. In the instance of software engineering, adaptability has become intrinsic to an engineer's capacity to develop alongside the technical landscape, which is in a constant state of flux. Paramount to this, is the aptitude to "apply divergent think whilst building a solution". Effectively, this concerns the capability to simultaneously explore various approaches to a unique problem, in parallel with generating creative ideas through these approaches, such that innovation becomes possible at a multitude of layers. This quality coincides with the diverse plasticity of an engineer's mindset and establishes circularity with the notion of subverting from the Einstellung phenomenon. Comprehensively, an engineer's portrait maintains a core of quantitative analytical capacities yet retains the deeper implications of an equilibrium between an innovative outlook and divergent thinking, to accompany the pragmatic persistence.

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[2] Guru Madhavan, "Mixing and Matching", In *Think Like An Engineer,* (Oneworld Publications, 2015), 21-26.
[3] Guru Madhavan, "Prototyping", In *Think Like An Engineer,* (Oneworld Publications, 2015), 154-156.

[3] Innovation as a Fuel for Social Impact

To compliment the application of technical knowledge in the translation of scientific theory to practical purposes, engineering is also founded upon the groundworks of facilitating healthy and constructive lifestyles. To do so, engineers innovate to pioneer new solutions or improve upon pre-existing ones. In either instance, the advancement of technology – not exclusive to digital devices – is delivered with a rationale: to enrich social context conditions. In conjunction with its facility to support social frameworks, products of engineering also preserve the ability to impair societal cohesion, often through long-term damages which are not noticeable or deemed negligible during the time of production.

George Bugliarello (1991), in *The Social Functioning of Engineering: A Current Assessment*, delineates a multifaceted feedback loop between the engineer and the society they serve. Within this professional configuration of dependency, communities employ the innovations of the engineer and diffuse them to widespread populations, extending the "power and reach of society and the individual"[4]. In the absence of this expansion, the discipline of engineering nor society would be able to progress ahead of a boundary of limitation, a threshold to our knowledge and productive capacity to support a growing population. This element of circularity between the designer and the user diminishes the margin of error for a detrimental technology by evaluating its implementation in a social context which testing may not accurately represent. The higher frequency and the more cohesion with which this circle of information functions, the less room there is for considerable social error. Despite this, the release of technology into society is impossible to fully reverse, and even with operation of the feedback loop, the cost-benefit analysis of the user in a higher frequency feedback loop will omit anything beyond the properties of imminent use. Thus, instances such as predicting the colossal carbon emissions of the most notable transportation innovation of human history, the automobile, are not a product solely of an engineer's lack of insight, but, more comprehensively, a misalignment of communication. Similarly, the catalytic decomposition of ozone in the atmosphere by CFCs emitted by computer chip manufacturing, may not be autonomously anticipated in the research laboratory.

As a result of these social impairments experienced when devices are employed over an extended time period, external system failure is often attributed to the engineer. This stems from a lack of understanding of the profession's social responsibility. To genuinely fuel social development through innovation, it is integral that both parties of the innovator and society understand the principles which pilot engineering interventions. Bugliarello, outlines these ideologies concisely as follows:

a) *Uphold the dignity of man.*
b) *Avoid dangerous or uncontrolled side effects and by-products.*
c) *Make provisions for consequence when technology fails.*
d) *Avoid buttressing social systems that perform poorly and should be replaced.*
e) *Participate in formulating the "why" of technology.*[5]

In his outline, Bugliarello defines the skeleton for successful interventions of engineering. Appreciating these guidelines improves the quality of the feedback provided and the device delivered as a product of the information cycle, improving the magnitude of positive constructive social impact.

In agreement with this proposition is Robert W. Lucky's (1991) *Pondering the Unpredictability of the Sociotechnical System*, where an emphasis is placed on the social acceptance of an engineer's innovation, whether the contribution be towards communication, education, or transport. The degree to which society will adopt new

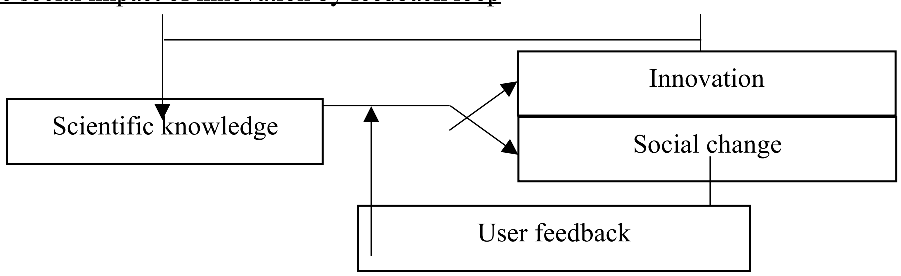
[4] George Bugliarello, "The Social Functioning of Engineering: A Current Assessment", *Engineering As A Social Enterprise,* (July, 1991): 73-75. https://doi.org/10.17226/1829.
[5] George Bugliarello, "The Social Functioning of Engineering: A Current Assessment", *Engineering As A Social Enterprise,* (July, 1991): 76-78. https://doi.org/10.17226/1829.

technology is challenging to forecast due to the unpredictability of human behaviour in product markets[6]. The frustration in attempting to quantify this criterion of innovative success is rooted in the concept that it is, by definition, always inaccurate to some extent or another. With an incomprehensible number of social parameters to account for there is simply no general model to map the psychology of the user. The implementation of market trials, focus group studies and comparisons to past technologies are all attempts to pinpoint and precisely determine the social impact innovation can create. Consequently, social approval of engineering interventions is volatile, with the opportunity for a technological macrocosm being only facilitated should an engineer's focused efforts be coordinated with social needs.

When expanding our paradigm towards the global community, a more holistic approach of assessing engineering's role may be adopted, which favours equity of outcomes. The software engineer's perspective proposes that the reflections and observations engineer's effectuate compile towards a "large data warehouse" which is accessible by the international public. However, to advance the accessibility of this platform, which networks the transfer of information, sustainable instruments and services must be delivered to those who lack integration in this global system. This requires the parallel development of novel solutions to established issues of informatic detachment. Widespread international accessibility to precise materials of innovation is, consequently, the large challenge we face in the forthcoming age of technical revolution.

In its condensed form, engineering's contribution to social progression through innovation can be provided by the following template:

Fig-2: Iterative social impact of innovation by feedback loop



[4] Fade-Out: Applying Engineering in Healthcare

When the diverse implications of the central themes discussed are effectively coordinated, the outcome of an engineering intervention can be experienced in a duality of progressive innovation and significant positive social impression. It is no revelation that medicine and healthcare, in their purest form, function around an axis of philanthropic services, immensely contributing to the welfare of our global community. However, in rural settings where access to the global network previously delineated is limited, the focus, precision and resourcefulness of engineering interventions must be augmented to facilitate adequate quality of care. A prime example of this synthesis can be identified in the rectification of acute power deficit in Uganda's rural Kisiizi hospital.

A direct testament to Bugliarello's first guiding principle of engineering conscience ("uphold the dignity of man"), the engineering methodology outlined in section [1] was applied to Kisiizi hospital's power shortage in order to transform an abundance of natural water resources from a nearby waterfall into a source of sustainable hydroelectric power for the growing community. The crucial efforts made are not solely a catalyst in the provision of quality clinical services by delivering 24/7 power to the hospital, however, upholds in coordination, the productivity of the local community through sale of electricity in addition to supplementing hospital finances with revenue surpluses. The purpose of discussing this solution is not to hold tribute to the feats of mechanical and electrical engineering

[6] Robert W. Lucky, "Pondering The Unpredictability Of The Sociotechnical System", *Engineering As A Social Enterprise,* (July, 1991): 89-92. https://doi.org/10.17226/1829.

accomplished in the regime of generators, despite this being noteworthy of recognition, but to appreciate and understand the application of the engineering approach intrinsic to resolving the social obstruction.

The groundworks for the eventual sustainable energy outcome were established during the Second World War, when a flax seed factory was built in Kisiizi to assist the war effort by providing linen chords used in parachutes. The industrialisation was marred though, by the spread of a fungal disease amongst crops, causing deterioration of the development venture. Amidst the apparent failure, Dr. Len Sharp envisioned opportunity, recognizing the hydroelectric potential of the location and the public demand for a church hospital. In this insight, Dr. Sharp considers the constant evolution engineering, by mode of his coordination of scientific knowledge applied to public needs. In conjunction, he upholds a vital dimension of the archetypal portrait of the engineering mindset with his persistence to independently initiate the project of transforming the flax factory into a functional hospital in 1958 – an unparalleled example of sustainable regenerative innovation. Presently, the dynamic system which was instructed over half a century ago has evolved productively into two generating hydroelectric sets, surrounded by a flow network which has been re-mapped following the adversity of floods, notably those of 2010 and 2020[7].

The system which now functions as an integral component of quality healthcare can be analysed through the engineering lens of forward-compatible design, a concept becoming more and more relevant in the modern day, as we face a drastic resource crisis. However, it has always been appreciated and implemented in social contexts where economic and communication fluidity is not abundant – where resources are limited, as outlined by a consultant specialist at Kisiizi. In the rural community, the mini-grid which harmonises electricity outputs through series of transformers and power lines, has been constructed with the possibility of future synchronisation with the national grid. Regardless of the technical and reliability issues this orchestration would entail, the expanded reach of sustainable energy is a favourable prospect given the 20th century current global climate. Kisiizi also looks towards the option of solar power, to reduce the strain on the hydroelectric sets, which are currently functioning at maximum capacity during the peak of demand. Methodically, the integration of these foresights into design considerably reduces the requirement for continuous mental and physical resource input to sustain productivity, particularly in a social context where these capitals are not abundantly available.

In parallel with recognising potential opportunities to enhance the quality of a system, it is vital that the challenges of a pressured system are also preempted. This incites the prerequisite of establishing priorities of function, the first phase of the innovation framework provided in section [1]. In this instance, quality healthcare provision by the hospital required consistent power, piloting the system design to isolate a hydroelectric set which is dedicated to the local hospital, preventing blackouts during generator overburden of commercial demand. Furthermore, in order to regulate and control generator input, a hydraulic pump mechanism manages water flow loads, proportional to the community demand for electricity during power production.

Concisely, the capacity of an engineer to forecast both the potential opportunities and impediments a system may experience beyond the security of the present, is a distinct indication of the adequacy of their mechanism's performance when confronted with the test of time and change. Fundamentally, it is not the technical knowledge an engineer possesses which determines his suitability in delivering operative contributions to innovation, but the degree to which he may translate this knowledge into social change. It is not the methodical and refined skill of analysis which defines the engineer, but the degree to which his aptitudes may translate into encouragement of the productive lifestyles of his peers. Engineering is practical and philanthropic, complex and collaborative. It is that which we can teach, apply, and weave into the social fabric of our global community.

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[7] "Power Company", *Kisiizi Hospital,* July 15, 2021. http://www.kisiizihospital.org.ug/?page_id=89.

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