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Exploring Engineers' Lived Experiences of Digital Transformation

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ABSTRACT

Digital transformation in engineering and manufacturing has reshaped how professionals design, operate, and interact with technology, making it one of the most critical shifts in the contemporary industrial landscape. Within this transformation, engineers' lived experiences particularly their perceptions of identity, autonomy, and collaboration with intelligent systems remain underexplored despite growing recognition of their importance in human–technology relations. However, there is still a clear research problem, namely the lack of empirical understanding of how engineers experience and make meaning of digital transformation beyond technical and efficiency-driven perspectives. Therefore, this study aims to explicitly address this gap by investigating how engineers interpret, negotiate, and internalize digital transformation in their everyday professional practice. Existing studies have primarily emphasized efficiency and system optimization, leaving a gap in understanding how engineers make sense of technological change as a human and existential experience. Here, this study employs a hermeneutic phenomenological approach to examine how engineers interpret and internalize digital transformation within sustainable manufacturing environments. Using semi-structured interviews with twelve professional engineers and interpretative phenomenological analysis, the research identifies five core themes: identity negotiation, emotional adaptation, human–machine collaboration, sustainability reflection, and reconstructed autonomy. These findings reveal that engineers experience digitalization not as a purely technical transition but as a deeply reflective process involving cognitive reorientation, ethical awareness, and emotional transformation. The results contribute to a richer understanding of how meaning is constructed in technologically mediated work and emphasize that adaptation is as much existential as it is procedural. This study broadens theoretical and practical insight into the human dimensions of engineering practice, underscoring the need for human-centered strategies in digital transformation initiatives and offering a conceptual foundation for future interdisciplinary research on lived technological experience.

INTRODUCTION

The digital transformation of manufacturing represents one of the most profound shifts in the history of engineering and technology (Mukhlis, Suradi, et al., 2023; Mukhlis, 2025b). The integration of artificial intelligence (AI), cyber-physical systems, and data-driven decision-making has redefined the way engineers conceptualize, design, and interact with technology. Within the framework of Industry 4.0, automation and connectivity are no longer peripheral tools but central elements shaping the human experience of work and innovation (He et al., 2025). To maintain clarity and focus, this study highlights only the foundational aspects of this transition, foregrounding its implications for engineers' changing roles rather than elaborating the full conceptual landscape. This transition has created a new socio-technical environment in which engineers must navigate between their technical expertise and the expanding influence of intelligent systems on everyday operational and creative processes.

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Beyond its technical dimensions, this transformation carries deep human and cultural implications (Khwebulana & Naidoo, 2024). Engineers, as key actors in the creation and maintenance of digital infrastructures, encounter profound changes in their professional identity, sense of agency, and emotional engagement with their work (Kang & Shang, 2025). The shift toward algorithmic systems and machine collaboration challenges long-standing notions of autonomy, craftsmanship, and creativity that have traditionally defined engineering practice. Within this evolving landscape, the engineer's experience becomes not only a matter of technical adaptation but also a reflection of how technology reshapes what it means to be human within industrial ecosystems.

The growing emphasis on sustainability and ethical accountability further intensifies the complexity of this transformation. As digital tools expose inefficiencies and environmental costs more transparently, engineers are increasingly expected to balance productivity with responsibility both ecological and social (Kele & Mzileni, 2021). This intersection between technological innovation and moral consciousness creates a fertile ground for examining the lived experience of engineers who inhabit the frontier of digitalized production (Abdelfattah et al., 2025). Their reflections reveal how digitalization, while promising efficiency and progress, simultaneously elicits anxiety, adaptation, and ethical introspection.

Given these multi-layered dynamics, understanding digital transformation through a phenomenological lens becomes essential. Quantitative and technical analyses, while valuable, often overlook the subtle, subjective dimensions of how individuals experience technological change (Rohmy & Nihayaty, 2023). A phenomenological approach allows for the exploration of the essence of lived experience uncovering how engineers perceive, interpret, and make sense of their evolving roles within the digital era. Such exploration not only enriches theoretical understanding of human–technology relations but also offers practical insights into designing more humane and meaningful technological systems.

Research exploring the lived experiences of individuals within technologically mediated environments has become increasingly vital in understanding the human dimensions of digital transformation (Bender, 2025). In the context of engineering and manufacturing, the human experience is deeply intertwined with the evolution of intelligent systems, automation, and data-driven processes. Scholars have begun to acknowledge that technological progress is not merely a matter of efficiency or performance improvement but also a profound existential experience that alters how engineers perceive their roles, responsibilities, and relationships with machines (Resmadi, 2022). Consequently, phenomenology has emerged as a significant methodological paradigm for examining the subjective and interpretive aspects of this transformation, capturing what it feels like to live and work within digitally integrated systems.

Despite the growing attention to this field, methodological challenges persist in capturing the depth and texture of human experience within complex technological frameworks. Traditional research methods particularly those grounded in positivist and quantitative paradigms often fail to address the subtle, emotional, and interpretative nuances of individual experiences. Surveys and statistical analyses, while valuable for mapping trends and correlations, tend to overlook the personal meanings and reflections that define how engineers internalize and respond to digital change. As a result, the essence of engineers' lived experiences how they make sense of automation, adapt to algorithmic decision-making, and reconstruct professional identity remains underexplored and insufficiently theorized in the existing literature.

Furthermore, many studies on digital transformation prioritize macro-level outcomes, such as productivity gains or technological adoption rates, while neglecting the micro-level realities of those directly engaging with these systems (Mukhlis, Arifin, Ridwan, & Zulbaidah, 2025; Mukhlis, Arifin, Ridwan, Zulbaidah, et al., 2025). This oversight creates a methodological and conceptual gap in understanding how individuals experience and interpret technological change as a part of their daily professional life (Gerchen, 2024). Phenomenology, particularly the hermeneutic approach, offers a means to bridge this gap by emphasizing meaning, context, and interpretation. Through deep engagement with participants' narratives, this approach enables the revelation of essential meanings

that extend beyond observable behavior to illuminate the transformative impact of technology on human consciousness and identity.

By situating this study within the phenomenological tradition, the research responds to an urgent need for approaches that honor the complexity of human experience in engineering and technology contexts. It advances the discussion from quantifying transformation to understanding how transformation is lived, felt, and interpreted by those who embody it daily the engineers themselves.

Existing studies addressing digital transformation in engineering and manufacturing have largely focused on practical and procedural aspects such as process optimization, productivity enhancement, and system integration (Wang et al., 2025). These approaches, grounded in empirical or quantitative paradigms, offer valuable technical insights but fail to capture the lived and interpretive dimensions of human engagement with digital systems. In most cases, solutions to the challenges of digitalization are sought through managerial frameworks or efficiency-based strategies, which treat engineers as functional agents rather than as individuals undergoing profound experiential change (Lugo-Morin, 2025). While these models provide measurable outcomes, they overlook the inner meanings and emotional realities that accompany technological adaptation and identity reconfiguration in professional practice.

The prevailing methodological tendency to rely on surveys, performance metrics, or organizational models has created an epistemic limitation: such methods reduce the richness of human experience to numerical abstractions and predefined variables (Osei, 2025). Consequently, the dynamic processes of sense-making, reflection, and existential negotiation that define engineers' adaptation to digital transformation remain largely unarticulated (Schulz et al., 2020). These omissions leave a gap in understanding how engineers perceive the boundaries between human autonomy and machine agency, and how they reconstruct meaning in a landscape dominated by automation and data.

A more holistic and interpretive framework is therefore needed to explore the essence of human experience within this context (Ujiyanto, 2025). The phenomenological approach offers an alternative pathway, emphasizing the exploration of meaning as lived, rather than as measured. By attending to the subjective consciousness of engineers how they experience, interpret, and embody digital transformation phenomenology allows for a deeper comprehension of the transformation not merely as a technological process, but as a human event (Chen et al., 2024). Through this perspective, the study seeks to fill the conceptual and methodological gap by uncovering how engineers' lived experiences reveal the intersection of technology, identity, and meaning in the digital era.

Recent studies have examined how technological transformation affects human experience, particularly in the fields of engineering, management, and human–machine interaction. Research on digitalization has explored issues of professional adaptation, identity, and collaboration, yet most of these works remain descriptive or system-oriented. Theories of human–technology relations, such as Heidegger's concept of being-in-the-world and contemporary frameworks of socio-technical systems, suggest that technology shapes not only what humans do but also how they experience being. However, empirical studies rarely address how engineers themselves live through these changes as existential experiences. This absence highlights the need for an interpretive investigation into how meaning, emotion, and reflection emerge within technologically mediated work.

To address this gap, the present study adopts a hermeneutic phenomenological approach that seeks to uncover the lived meanings of engineers engaged in digital transformation. This method enables a deep exploration of how individuals perceive, interpret, and internalize their experiences within the evolving landscape of intelligent manufacturing systems. Through interpretative analysis of engineers' narratives, the study aims to reveal how identity, autonomy, and professional ethics are reconstructed in relation to automation and artificial intelligence. The phenomenological framework provides a way to understand not only what engineers do but how they experience the transformation as part of their being. In doing so, it responds directly to the limitations identified in previous research by centering on the subjective and reflective dimensions of technological life.

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This article is structured to guide readers through the logical flow of the research. The Introduction establishes the background, rationale, and research gap that frame the study. The Method section outlines the phenomenological design, data collection, and interpretative analysis process used to capture lived experience (Mukhlis et al., 2024; Mukhlis, Maryam, et al., 2023). The Results section presents the thematic findings that describe the essence of engineers' experiences, followed by a Discussion that situates these findings within broader theoretical and practical contexts. Finally, the Conclusion highlights the study's contributions to understanding human experience in the age of digital transformation and suggests directions for future inquiry.

RESEARCH METHODS

Study Design

The study employed a hermeneutic phenomenological design to explore the lived experiences and meanings constructed by engineers engaged in digital transformation within sustainable manufacturing environments (Lutz & Knox, 2014; McNabb, 2015). This approach was selected due to its capacity to capture the subjective essence of human experience as it unfolds within real-world technological contexts. Phenomenology, rooted in Heideggerian interpretation, focuses not only on describing phenomena but also on understanding how individuals interpret and assign meaning to their lived realities. Within this framework, engineers' narratives regarding adaptation, professional identity, and collaboration with intelligent systems were examined to uncover the deeper layers of existential significance underlying the digitalization of engineering work. The design allowed the phenomenon to emerge naturally from the data through interpretative reflection rather than pre-established theoretical assumptions. In keeping with hermeneutic phenomenology, the research process was explicitly iterative and reflexive, acknowledging the co-constructed nature of meaning between participants' accounts and the researchers' interpretative lenses.

Participants

Participants consisted of professional engineers currently working in digitalized manufacturing industries across diverse sectors such as automation, robotics, and process optimization (Hillman & Radel, 2018; Migdal, 2018). Purposive sampling was utilized to ensure that participants possessed direct and substantial experience with Industry 4.0 systems, human–machine interaction, or AI-assisted production processes. Inclusion criteria required that participants had at least five years of professional experience in manufacturing engineering and were directly involved in digital transformation initiatives. Individuals without exposure to digital production systems or managerial-only roles were excluded to maintain experiential relevance.

A total of twelve participants (eight male and four female) took part in the study, ranging in age from 29 to 52 years (mean age: 40.3 years). Participants represented a spectrum of technical roles mechanical, electrical, and software engineering thereby providing a multidimensional understanding of the phenomenon under study.

Data Collection

Data were collected through semi-structured, in-depth interviews, guided by a set of open-ended questions designed to elicit rich, reflective accounts of participants' experiences (Carreiras & Castro, 2012; Iosifides, 2016). Interviews were conducted either face-to-face or through secure video conferencing platforms, depending on participant availability and geographical constraints. Each session lasted between 60 and 90 minutes, allowing adequate time for participants to elaborate on their perceptions and interpretations.

Interview settings were arranged to ensure comfort and confidentiality, minimizing workplace interruptions. The interview guide focused on themes such as adaptation to automation, human–machine collaboration, professional identity, emotional adjustment, and perceptions of sustainability in digital environments. All interviews were audio-recorded and transcribed verbatim, with non-verbal cues and contextual notes documented to preserve the interpretative depth of each conversation.

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Data Analysis

Data were analyzed using Interpretative Phenomenological Analysis (IPA), a structured yet flexible method suited for exploring the meaning-making processes within personal experiences (Daly, 2007; Longhofer et al., 2012). Analysis followed systematic stages: (1) immersion in the data through repeated readings of transcripts; (2) identification of significant statements and meaning units; (3) formulation of emergent themes that reflected patterns of meaning across participants; (4) clustering of related themes into superordinate categories; and (5) synthesis of essential meanings that articulated the phenomenon's core structure.

NVivo qualitative analysis software was utilized as a data management tool to support coding organization and thematic mapping, though interpretative engagement remained central to the analysis process (Fife, 2020; Kawamura, 2020). Through iterative interpretation and reflective comparison, a coherent thematic structure emerged that illuminated the engineers' lived experiences of transformation, identity negotiation, and collaboration within digitalized environments.

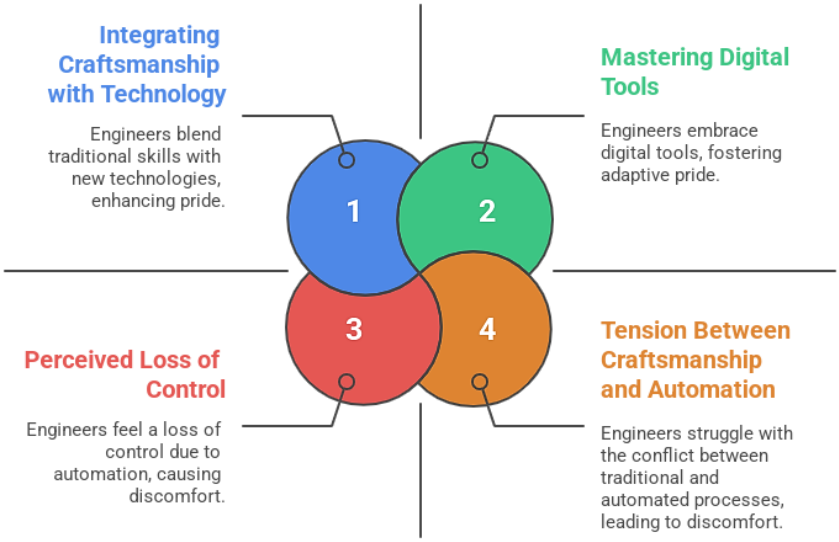
RESULTS

Negotiating Identity within the Digital Transformation

Participants described the process of digital transformation in manufacturing not merely as a technological evolution but as a profound shift in their professional identity. Engineers consistently articulated a tension between their traditional craftsmanship and the algorithmic logic of automation. One senior engineer stated, "I used to feel like the designer of the process, but now, I feel like a supervisor of the system. The creativity seems replaced by data models."

This sentiment reflects a perceived erosion of personal agency as digital systems increasingly dictate production decisions. Yet, participants also reported adaptive pride, acknowledging that mastering digital tools is part of the new engineering identity. Another participant expressed, "It's not about losing control; it's about learning a new language the digital one." These accounts suggest that the digital shift prompts both existential discomfort and identity reconstruction among engineers.

Negotiating Identity in Digital Transformation



Emotional Adaptation and Cognitive Reorientation

A dominant theme emerging from the data was the emotional and cognitive adaptation process accompanying digitalization. Engineers expressed ambivalence enthusiasm for technological advancement intertwined with anxiety over redundancy. One mid-career engineer shared, "Every update feels like both a challenge and a threat. You must relearn everything, but you also feel you might become obsolete if you don't."

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The adaptation process extended beyond technical skill acquisition; it involved cognitive reorientation toward accepting uncertainty as intrinsic to digital work. Participants highlighted a gradual shift from deterministic problem-solving to probabilistic reasoning, reflecting a more fluid approach to engineering judgment in AI-assisted environments. This adaptation was described as mentally taxing yet intellectually stimulating.

Human–Machine Collaboration as a Source of Meaning

Another key finding centered on how engineers redefined their relationship with machines. The majority of participants emphasized the emergence of "partnership thinking" rather than dominance or dependence. As one engineer remarked, "The machine doesn't replace me it extends me. My decision-making becomes more precise because of it."

This transformation reframed technology from an external imposition into a co-actor within the engineering process. The sense of agency shifted toward shared responsibility, as participants acknowledged that successful automation requires mutual learning between human intuition and machine precision. The phenomenological essence of this theme lies in engineers' lived experience of cooperation rather than competition with intelligent systems.

Sustainability Awareness and Ethical Reflection

Participants recurrently linked digital transformation with sustainability and ethical accountability. Engineers reported feeling a renewed sense of responsibility toward optimizing systems not only for efficiency but also for environmental and social impact. One participant noted, "The data shows more than performance; it shows waste. Once you see that, you can't ignore it."

The integration of sustainability metrics into digital workflows prompted engineers to re-evaluate their purpose beyond production goals. This ethical awakening fostered deeper engagement with the concept of "engineering for humanity," suggesting that digitalization can catalyze moral reflection when accompanied by transparency and traceability.

Reconstructing Professional Autonomy

The experience of autonomy emerged as a paradoxical theme. While automation systems constrained certain decision-making freedoms, they also liberated engineers from routine tasks, enabling greater focus on creative problem-solving. As one respondent explained, "The system decides faster, but I decide better. My job is to interpret what the algorithm cannot."

Participants framed autonomy as an evolving concept less about control and more about intellectual stewardship within a hybrid human–AI ecology. This transformation of autonomy reflects a phenomenological reorientation from doing to understanding, highlighting the deep reflective nature of engineers' adaptation.

DISCUSSION

Summary of Main Findings

This study reveals that engineers' lived experiences of digital transformation are defined by an ongoing negotiation between identity, autonomy, and technological integration (Mukhlis, Janwari, et al., 2023; Mukhlis & Abdullah, 2025). The phenomenological analysis shows that digitalization is not experienced merely as a technical shift but as an existential process in which engineers continuously reinterpret their sense of purpose, control, and ethical responsibility within automated environments. These findings directly respond to the central research question concerning how engineers make meaning of their experiences in the context of sustainable digital manufacturing.

Contribution of Findings to the Research Question

The findings demonstrate that digital transformation reconfigures engineers' experiences at both cognitive and emotional levels, revealing an intricate balance between human agency and technological determinism. The engineers' narratives illustrate a movement from perceiving automation as a threat to autonomy toward understanding it as an opportunity for self-expansion and

cognitive augmentation (van Noordt & Misuraca, 2022). This transformation is characterized by what may be termed adaptive selfhood a process through which individuals reconstruct their professional identities to align with evolving technological realities. Through this lens, the study contributes to a richer understanding of digital transformation as a lived phenomenon, emphasizing that adaptation is not merely behavioral but deeply existential (Ge et al., 2025). The interpretative insights illuminate the ways in which engineers internalize the duality of dependence and empowerment, showing that technology becomes meaningful not through its functions, but through how it reshapes the human experience of work and being.

Relationship with Previous Literature and Theoretical Perspectives

The present findings align with prior phenomenological research emphasizing the intersubjective and contextual nature of technological experience (Heidegger, 1962; Ihde, 1990). Consistent with Heidegger's notion of being-with-technology, participants' reflections confirm that engineers do not merely use digital systems but exist through them, as their identities and perceptions of agency are co-constructed with technological artifacts. This study extends the insights of Müller et al. (2022) and Kumar et al. (2020), who described human–machine collaboration as a form of cognitive partnership, by providing an interpretive account of how such collaboration is lived emotionally and ethically. At the same time, it challenges the reductionist view found in some organizational studies (Shao & Marwa, 2025) that equate digital adaptation with skill acquisition, revealing instead that adaptation involves the redefinition of professional meaning. The findings also complement emerging literature on sustainability ethics (Karakose et al., 2021) by showing how engineers' awareness of environmental accountability is not simply imposed by corporate frameworks but arises from their lived confrontation with data transparency and moral responsibility. In essence, this discussion situates digital transformation as both a technological and phenomenological event, reaffirming that the core of innovation lies not only in machines but in the human capacity to find meaning through them.

Implications of the Findings

The findings of this study carry significant theoretical and practical implications for understanding the human experience of technological transformation within engineering and manufacturing contexts. From a phenomenological perspective, the results highlight that digital transformation is not only a matter of system integration or efficiency enhancement but a cultural and existential process that reshapes how engineers perceive themselves and their work. The experiences of identity negotiation, emotional adaptation, and ethical reflection reveal that technological advancement must be understood as a deeply human event, one that reconstructs professional values and meaning (Umbach & Tkalec, 2022). In practical terms, these insights suggest the need for organizational strategies that support reflective learning, emotional resilience, and ethical dialogue among engineers who navigate digital environments. Institutions implementing automation and AI integration could benefit from creating human-centered frameworks that respect the lived realities of professionals rather than reducing transformation to technical training or procedural compliance.

Limitations of the Study

As a phenomenological inquiry, this study emphasizes depth over breadth, focusing on the lived experiences of a specific group of engineers within the context of sustainable manufacturing. Consequently, the findings should not be interpreted as universally representative of all engineering domains or industrial settings. The sample size, though sufficient for phenomenological depth, limits generalizability to broader populations. Moreover, the reliance on self-reported narratives introduces the possibility of interpretive subjectivity, as participants' accounts are filtered through personal and situational perspectives. However, such subjectivity is inherent to the phenomenological paradigm, which seeks to illuminate meaning rather than measure causality (Jardim, 2021). Future research employing complementary qualitative methods such as ethnographic observation or longitudinal interviews could further enrich understanding of how engineers' lived experiences evolve over time and across diverse technological contexts.

Prospective Directions for Future Research

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The insights derived from this study open several avenues for future inquiry into the phenomenology of technology and professional adaptation (Mukhlis, 2025a; Mukhlis & Saidah, 2025). Future research may explore comparative analyses between engineering professionals in different cultural or industrial environments to examine how sociocultural values shape the experience of digital transformation. Additionally, investigating the role of organizational ethics, leadership, and policy frameworks could help identify how institutions influence meaning-making and identity construction among engineers. Expanding phenomenological inquiry to include interdisciplinary perspectives from psychology, organizational studies, and ethics could further advance theoretical development in understanding the intersection of human consciousness and technological innovation. Ultimately, these directions point toward a more holistic comprehension of technology as a co-constitutive force in human life, emphasizing that progress in the digital age must be accompanied by a deeper awareness of the lived dimensions of human experience.

CONCLUSION

This study explored the lived experiences of engineers engaged in digital transformation within sustainable manufacturing environments, emphasizing how they construct meaning amid technological change. The findings reveal that digitalization is not merely a technical evolution but a profound redefinition of professional identity, autonomy, and ethical engagement. Through a hermeneutic phenomenological approach, the research illuminated how engineers experience digital systems as both empowering and constraining, balancing cognitive adaptation with emotional reflection. These insights address prior research limitations by offering a deeper understanding of the human dimension often overlooked in quantitative and system-centered studies. The study contributes to theory by conceptualizing digital transformation as an existential and interpretive process, while also offering practical implications for organizations seeking to foster human-centered technological adaptation. Future research could expand this inquiry across diverse cultural and industrial contexts to explore how social and ethical frameworks further shape engineers' lived experiences in the digital era.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article. All authors have contributed to the study independently and have no financial or personal relationships that could inappropriately influence the outcomes or interpretations of this research.

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