

Abstract

This study investigates how Additive Manufacturing (AM) functions as a catalyst for workflow transformation in industrial design practice, reframing AM not as a disruptive technology but as a driver of structural and epistemic change. Using a practice-based autoethnographic methodology, the study draws on twenty years of professional and pedagogical experience, supported by a thematic synthesis of over fifty academic and professional sources and validated through member checking with academic peers. Two physical case projects -a tugboat model and a mechanical gearbox redesign for electric conversion- serve as the empirical basis, together with the hybrid CAD-to-game-engine workflow integrated into both projects' additive manufacturing pipelines. The findings identify three interrelated dynamics: the decentralization of design authority, enabling direct designer oversight of fabrication parameters; the reconfiguration of linear workflows into recursive, integrated loops, associated with a self-reported, substantial reduction in development time; and the emergence of a hybrid "designer-maker-engineer" role combining creative intuition, computational modeling, and material-process literacy. The study situates these shifts within the technical constraints of hybrid fabrication, including process optimization and surface-quality considerations in secondary manufacturing operations. The article concludes by discussing the tension between creative freedom and manufacturability and proposing implications for design education aimed at cultivating integrative, hands-on competencies for agile practice.

Keywords: Additive Manufacturing; Industrial Design; Autoethnography; Workflow Transformation; Designer-Maker-Engineer;

A Practice-Based Autoethnographic Investigation of An Industrial Designer's Workflow Transformation

Endüstriyel Tasarımcının İş Akışı Dönüşümünün, Uygulama Temelli Otoetnografik İncelenmesi

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Genişletilmiş Özet

Araştırma Sorusu ve Hedefler: Eklemeli üretim (AM), başlangıçta yalnızca erken aşama prototipleme süreçlerine yönelik bir araç olarak görülse de, günümüzde ürün geliştirme, kitlesel özelleştirme ve dağıtık imalat süreçlerine entegre olan gelişmiş bir üretim teknolojisi haline gelmiştir. Bu teknolojik evrim, tasarımcıların yaratıcı imkânlarını genişletmekle kalmamakta, aynı zamanda tasarım metodolojilerini, profesyonel rolleri ve tasarım bilgisinin üretilme biçimlerini yapısal olarak yeniden şekillendirmektedir. Geleneksel endüstriyel tasarım pratikleri, fikir geliştirme (ideasyon) ile üretim aşamalarını birbirinden kesin çizgilerle ayıran doğrusal bir iş akışında kurgulanmıştır. Bu geleneksel yapıda tasarımcılar eskizler, spesifikasyonlar ve modeller üretir; bu çıktılar daha sonra harici mühendisler ve üreticiler tarafından yorumlanarak fiziksel nesneye dönüştürülür. Ancak eklemeli üretim, dijital kavram ile fiziksel nesne arasındaki mesafeyi daraltarak bu ayrımı ortadan kaldırmaktadır. Bu çalışmanın temel araştırma sorusu, eklemeli üretimin salt teknik bir araç olmanın ötesinde, endüstriyel tasarım pratiğinde nasıl yapısal ve epistemik bir değişim katalizörü görevi gördüğüdür. Araştırmanın temel hedefi, bu teknolojinin tasarımcıların düşünme, iş birliği süreçlerini yürütme ve eylem (making) yoluyla bilgi üreteye yöntemlerini nasıl dönüştürdüğünü derinlemesine incelemektir.

Yöntem: Çalışmada, endüstriyel tasarım pratiğindeki kültürel ve epistemik dönüşümleri incelemek amacıyla analitik otoetnografi metodolojisi benimsenmiştir. Bu yöntem, yazarın yirmi yıllık profesyonel ve pedagojik deneyimini birincil veri kaynağı olarak konumlandırarak, katılımcıların izlenmesi veya mülakat gibi yöntemlerin ulaşamayacağı "örtük" ve "durumsal" bilgilere erişim sağlamaktadır. Analiz süreci, endüstriyel tasarım iş akışları ile eklemeli üretimin kesişimine odaklanan elliden fazla akademik ve mesleki kaynağın tematik sentezi ile desteklenmiştir. Araştırmanın ampirik temelini yazarın kendi pratiğinden seçilen iki fiziksel vaka çalışması oluşturmaktadır: karmaşık gövde geometrisine sahip Arktik sınıfı bir römorkör projesi ve elektrikli moped dönüşümü için yeniden tasarlanan mekanik bir dişli kutusu; bu iki projenin eklemeli üretim iş akışına entegre edilmiş hibrit bir CAD-oyun motoru iş akışı da ayrıca incelenmektedir. Bulguların güvenilirliğini artırmak için akademik akran denetimi (member checking) süreci yürütülmüştür.

Bulgular ve Tartışma: Refleksif analiz süreci sonucunda, endüstriyel tasarım pratiğini dönüştüren üç temel dinamik saptanmıştır. İlk dinamik, tasarım otoritesinin ademi merkezileşmesidir. Geleneksel üretim sistemlerinde tasarım kararları imalat katmanlarından geçerek filtrelenirken, eklemeli üretim tasarımcının katman yükseklığı, dolgu oranı ve malzeme özellikleri gibi üretim parametreleri üzerinde doğrudan denetim sahibi olmasını sağlamaktadır. Arktik römorkör projesinde belgelendiği üzere, karmaşık geometrilerin harici kalıp süreçlerine ihtiyaç duyulmadan doğrudan üretilebilmesi, tasarımcıya teknik kısıtlar dahilinde eşsiz bir deneysel özgürlük tanımaktadır.

İkinci temel bulgu, doğrusal iş akışlarının özyinelemeli (recursive) döngülere dönüşmesidir. Geleneksel "üreticiye teslim" (hand-off) aşaması yerini tasarım, simülasyon ve fiziksel testlerin iç içe geçtiği bütünlük bir süreç bırakmıştır. Elektrikli moped dişli kutusu projesinde görüldüğü gibi, tasarım ve üretim aşamalarının bu denli iç içe geçmesi, ürün geliştirme sürecinde niteliksel olarak belirgin bir azalma sağlamıştır. Bu durum, tasarım sürecinin önceden belirlenmiş bir bitiş noktası olan "üretim için tasarım" anlayışından, dinamik bir problem çözme süreci olan "sürekli tasarım" anlayışına evrildiğini göstermektedir.

Üçüncü olarak, yaratıcı sezgiyi teknik uzmanlık ve malzeme okuryazarlığı ile birleştiren hibrit bir "tasarımcı-yapımcı-mühendis" rolünün ortaya çıktığı gözlemlenmiştir. Bu yeni rol, estetik kararlar ile lazer kesim parametreleri, yüzey pürüzlülüğü tahmini ve malzeme deformasyonu gibi teknik kısıtları eşzamanlı olarak yönetebilme yetkinliğini gerektirmektedir. CAD verilerinin Unreal Engine gibi oyun motorlarına aktararak malzeme özelliklerinin dijital ortamda veri odaklı olarak test edildiği iş akışı, bu hibrit kimliğin somut bir yansımasıdır. Ancak bu süreçte, tasarım özgürlüğü ile üretilebilirlik arasındaki gerilim, sürekli bir müzakere alanı olarak varlığını sürdürmektedir.

Sonuç: Araştırma sonuçları, endüstriyel tasarımda kapsamlı bir epistemik kaymaya işaret etmektedir: Tasarım bilgisi artık yalnızca çizimler ve şartnamelerle dışallaştırılmamakta; aksine üretim edimi (making) aracılığıyla doğrulanan ve fiziksel nesneye kurulan doğrudan etkileşimle şekillenen bir yapıya bürünmektedir. Üretilebilirlik artık tasarım sürecinin sonunda ele alınan teknik bir detay değil, yaratıcı süreci en başından itibaren yönlendiren aktif bir parametredir. Bu dönüşüm, tasarım eğitimi için de kritik çıkarımlar sunmaktadır. Mevcut eğitim modellerindeki "beceri siloları" yerine, dijital akıcılık, malzeme okuryazarlığı ve doğrudan üretim deneyimini birleştiren bütünlük bir pedagojik modele geçilmesi gerektiği vurgulanmaktadır. Sonuç olarak, eklemeli üretim, endüstriyel tasarımcıyı sadece form veren bir aktör olmaktan çıkarıp, tasarımın teknik, kültürel ve malzeme boyutlarını bütünlüştürmüş bir biçimde yöneten bir teknoloji yöneticisine dönüştürmektedir.

Keywords: Eklemeli Üretim; Endüstriyel Tasarım; Otoetnografi; İş Akışı Dönüşümü; Tasarımcı-Yapımcı-Mühendis;

1 Introduction

Additive manufacturing (AM), widely referred to as 3D printing, has shifted from a rapid prototyping tool to a production technology integrated into product development, mass customization, and distributed manufacturing systems (Sossou et al., 2018). This shift has expanded designers' creative possibilities while also reshaping design methodologies, professional roles, and underlying assumptions about how design knowledge is produced (Savvides, 2021).

Industrial design (ID) has traditionally operated between engineering precision and aesthetic judgment (Forsey, 2013), within workflows that separate ideation from fabrication (Ary S., 2024): designers produce sketches, specifications, and CAD models that are then interpreted and realized by external engineers and manufacturers (Self, 2012). AM challenges this separation. By compressing the gap between digital concept and physical artifact, it enables iterative cycles that are more entangled and recursive than in conventional pipelines (Gulay & Lucero, 2019), allowing design decisions to be tested and refined directly within the digital-to-physical loop (Tao et al., 2019).

This article approaches AM as a catalyst for change in design culture and epistemology, rather than as a disruptive technology in purely economic or mechanical terms. The aim is to understand how AM affects the way designers think, collaborate, and produce knowledge through making. To this end, the study adopts a practice-based autoethnographic methodology, drawing on the author's twenty years of professional and pedagogical experience in industrial design and engineering. Personal project archives and classroom observations are treated as primary sources of situated and tacit knowledge. Drawing on case studies from the author's own practice -including the development of an Arctic-class tugboat with complex hull geometries and a mechanical gearbox redesigned for electric conversion- this inquiry examines three interrelated transformations: the decentralization of design authority, the reconfiguration of

design workflows into recursive loops, and the emergence of a hybrid "designer-maker-engineer" role.

This reflexive analysis is grounded in a thematic synthesis (Thomas & Harden, 2008) of more than fifty academic and professional sources. Sources were included only if they addressed the intersection of AM and industrial design workflows, professional roles, or design epistemology; studies focused solely on the mechanical properties of materials or on engineering applications without implications for the design process were excluded. This criterion guided the inclusion of recent technical research on multi-objective optimization, AI-assisted quality predictions, and surface characteristics. These studies are essential because they define the manufacturability constraints that the 'designer-maker-engineer' must navigate within an integrated design responsibility. By combining this technical literature with reflexive personal practice, the study positions AM as a catalyst for systemic change across both the cultural and technical dimensions of design.

It is important to be precise about what this study adds to already substantial literature. That AM narrows the gap between designer and maker, and that it accelerates iteration, are established observations (Gulay & Lucero, 2019; Tao et al., 2019); this article does not contest them. Its contribution is different in kind: rather than documenting the existence of these trends at the level of technology or organization, it provides a longitudinal, practitioner-level account of how they are enacted within practice. Drawing on documented project archives, it traces how decentralization of authority, workflow recursion, and role hybridization interact and reinforce one another over time within a single practice, and examines what these interactions imply for the validation of design knowledge itself (Section 5.1). The three-dynamic model developed in Section 3, and the explicit coding process used to derive it (Section 4.1), are offered as a framework that future multi-practitioner studies can test, rather than as a claim that

AM's designer-maker convergence is being reported here for the first time.

2 Background Literature and Theoretical Framework

This section reviews the interdisciplinary literature that frames the autoethnographic analysis presented in the following sections, addressing the evolution of AM as a production technology, its epistemological implications for design knowledge, the reconfiguration of design workflows, the technical constraints of hybrid fabrication, the blurring of professional roles, and the theoretical lenses adopted in this study.

2.1 From Prototyping to Production

AM was initially valued for its ability to rapidly translate digital models into physical prototypes, accelerating iteration and shortening development cycles (Gibson et al., 2015; Ree, 2011). As the technology matured, it expanded to support the direct production of functional parts and finished products (Tofail et al., 2018), particularly for components requiring complex geometries or bespoke customization (Egon et al., 2024).

This expansion alters the traditional sequential design-to-production process (Friesike et al., 2019). Rather than a linear hand-off from design to manufacturing, AM enables an integrated approach in which the digital model functions as a living artifact, continuously refined through cycles of simulation and fabrication (Stefanescu, 2020). Projects requiring high precision and material integrity illustrate this integration well. This integration is illustrated in Figure

1, which shows the progression from a 3D model through the printing process to the final physical product, a sequence that, in AM-integrated practice, is not a one-way pipeline but a recursive loop subject to continuous revision.

2.2 Making as Knowledge Production

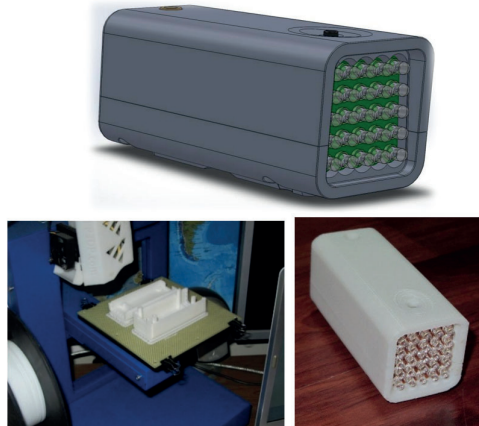
A central premise of this inquiry is that AM challenges established assumptions about how design knowledge is generated and represented. In conventional practice, design knowledge is largely externalized through drawings and specifications (Self, 2012). In AM-integrated practice, however, knowledge production becomes closely tied to the act of making: fabricating physical artifacts generates “tacit” and “situated” insights that are difficult to articulate through verbal or graphic means alone (Cordeiro-Nilsson & Hawamdeh, 2011; Diegel et al., 2019).

Direct manipulation and observation of material behavior during fabrication deepen the designer's understanding of the artifact (Venkatesh, 2021). This material engagement supports creative risk-taking, as sensory feedback from physical models offers immediate validation or contradiction of digital assumptions.

2.3 From Linear Pipelines to Recursive Loops

Traditional ID workflows are often described, in simplified terms, as a phased, linear progression: research, concept, design, prototyping, and production, in which each stage is completed before the next begins and fabrication remains external to the design process itself. It is worth noting that much of the design-methodology literature already characterizes this progression as iterative rather than strictly linear, with recurring cycles of divergence and convergence across concept development and evaluation (de Vere, 2013); the simplified linear description above is a baseline for contrast, not a claim that iteration is absent from conventional design methodology. What distinguishes the AM-integrated workflow examined later in this article is not the introduction of iteration

Figure 1: Product 3D model, printing process, and the final product (Author's work)



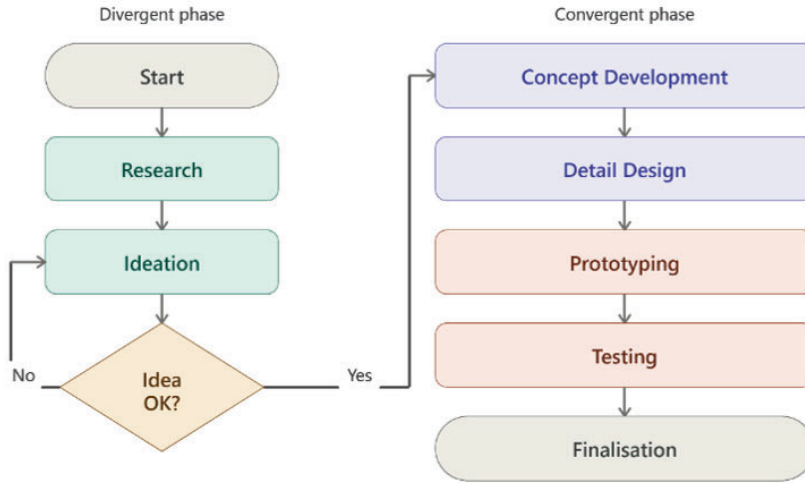


Figure 2: Traditional industrial design workflow (Author's diagram).

as such, but the collapse of the physical hand-off between design and fabrication, which allows iteration to occur through direct material production rather than only through digital planning cycles. As shown in Figure 2, this sequential structure separates the divergent phase of ideation and research from the convergent phase of development and production, positioning manufacturing as a downstream endpoint rather than an active participant in design decision-making.

AM disrupts this sequence by enabling recursive loops that merge these phases into a more continuous process, allowing experimentation with form and function at finer granularity. The ability to simulate performance digitally while simultaneously fabricating physical models supports a mode of working in which design knowledge develops dynamically through making (Negendahl, 2015).

2.4 Technical Boundaries in Hybrid Fabrication

A central challenge for designers working with AM and hybrid fabrication processes is navigating the technical boundaries that constrain manufacturability. Recent studies illustrate the scope of these constraints in detail. Using a fuzzy AHP-based multi-criteria decision-making (MCDM) approach, one study optimized laser-cutting parameters for polyethylene, identifying trade-offs between cutting speed, kerf quality, and material deformation that

designers must anticipate when specifying secondary processes for printed parts (Basar & Der, 2025). While such methods are used for technical process optimization, it's been previously demonstrated that adapting AHP and PROMETHEE tools to the evaluation of 3D-printed design alternatives increases objectivity and accuracy in the decision-making process, ultimately enhancing overall design quality (Özsoy, 2019). A related study applied AI-based hybrid metaheuristic optimization to predict surface roughness and kerf width in CO2 laser cutting of 3D-printed PLA-CF composites, demonstrating that print orientation and infill parameters chosen at the design stage have measurable downstream effects on post-processing quality (Basar et al., 2025). A third study examined the surface characteristics of 3D-printed PET-G plates subjected to CO2 laser cutting, showing how material choice and printing parameters interact with secondary finishing operations to affect dimensional accuracy and surface integrity (Kechagias et al., 2022).

Together, these studies indicate that decisions traditionally considered “downstream” of design -material selection, print orientation, and finishing strategy- now carry direct design implications. For the designer working in an AM-integrated practice, this means that technical optimization is not external to the creative process but an active constraint that shapes it from the outset.

2.5 Interdisciplinary Hybridity: The Designer-Maker-Engineer

As AM becomes embedded in practice, professional roles increasingly overlap. The designer's role extends from generating aesthetic concepts to managing material science, engineering constraints, and complex digital workflows (Koch, 2022), giving rise to what this study terms the "designer-maker-engineer" (Özsoy, 2012).

This hybrid role requires fluency in algorithmic logic and generative design (Mandolini et al., 2022). The combination of creative intuition with computational rigor allows designers to evaluate material and physical properties in digital environments before committing to a physical print.

2.6 Theoretical Framework: Sociotechnical and Practice-Based Perspectives

This study draws on two complementary theoretical lenses: a sociotechnical perspective, which views AM as embedded within a network of human actors, organizational structures, and material infrastructures rather than as a standalone tool; and practice-based design theory, which foregrounds the embodied, material dimension of design work (Self, 2012).

These perspectives were selected over alternatives such as actor-network theory or innovation diffusion theory because the study's central concern is not the adoption trajectory of AM as an innovation, nor the symmetrical agency of human and non-human actors in a network, but the lived, first-person experience of a practitioner whose professional identity and workflows are reshaped through sustained material engagement. Sociotechnical and practice-based perspectives are better suited to an autoethnographic design that treats the researcher's own practice as data: the former

situates individual practice within broader organizational and technological structures, while the latter provides the conceptual vocabulary -tacit knowledge, situated learning, material engagement- needed to interpret that practice. Together, these lenses inform the analysis of how AM reshapes not only design outputs, but the professional identity of the person producing them.

3 Reflexive Analysis of Practice

This section presents a reflexive analysis of the author's professional and pedagogical practice, organized around the three central dynamics introduced earlier: the decentralization of design authority, the reconfiguration of workflows into recursive loops, and the emergence of the "designer-maker-engineer." Each theme is grounded in specific project archives and discussed in relation to the theoretical framework outlined in Section 2.

3.1 Decentralization of Design Authority

In conventional manufacturing systems, design decisions are typically filtered through multiple layers of engineering and production management before reaching physical form (Okuda, 2001). AM has enabled a redistribution of this authority, allowing the author to engage directly with fabrication technologies and collapse the boundaries between design, prototyping, and production (Bogers et al., 2015).

This shift is most evident in the Arctic-class ocean-going tug project. By controlling the digital-to-physical loop directly, the author maintained oversight of fabrication parameters, complex hull geometries, and fine structural details without relying on external tooling services or interpretative intermediaries. As shown in Figure 3, the project involved translating a highly complex hull geometry -with fine structural details that would have required extensive external tooling in a conventional workflow- directly into a physical artifact via AM, demonstrating the degree of fabrication control that decentralized authority enables. This direct control supported a degree of experimental freedom -particularly in iterating on hull geometry-that would

Figure 3: Arctic class ocean-going tug 3D model with complex hull lines, fine details, and printed project (Author's work).



have been cost-prohibitive in a traditional outsourced workflow (Lodato & DiSalvo, 2018).

Beyond efficiency, this decentralization changes the relationship with clients. The capacity to produce on-demand physical iterations supports a more participatory dynamic, in which clients engage with successive physical prototypes rather than only with drawings or renders. This blurs conventional distinctions between author, maker, and client in the design process, but it also introduces new challenges: as fabrication moves in-house, questions of quality assurance and intellectual property become the designer's direct responsibility rather than that of a separate manufacturing partner (Steenhuis & Pretorius, 2017).

3.2 Reconfiguration of Workflows: From Linear Pipelines to Recursive Loops

The transition from a linear, stepwise workflow to a recursive, integrated loop has been the most significant structural change in the author's daily practice. In the traditional model, a "hand-off" to a third-party manufacturer typically marks the end of the design phase. With AM, design, simulation, and physical testing occur in rapid, overlapping cycles (Kim et al., 2015).

This reconfiguration is documented in the development of mechanical gearbox assemblies for electric moped conversion. By merging design and fabrication phases, the author was able to move fluidly between virtual and physical representations,

incorporating fabrication constraints -including those related to the surface-finishing trade-offs discussed in Section 2.4- from the earliest stages of ideation (Gulay & Lucero, 2019). Figure 4 documents this recursive workflow across three stages: the CAD model with assembly simulation, the 3D-printed prototype used for fit and function testing, and the final product manufactured in CNC, each stage informing the next in a continuous loop rather than representing a discrete hand-off between design and production.

Across the gearbox and tug projects, this recursive approach is associated with a self-reported, substantial reduction in overall development time, compared to the author's prior experience with linear, outsourced workflows on comparable projects. This assessment is based on the author's own project timelines rather than a controlled or externally validated measurement, and is deliberately not expressed as a specific percentage for the reasons discussed in Section 5.3; it has not been benchmarked against equivalent projects completed by other practitioners or teams. Its value lies less in its precision than in the qualitative shift it reflects: a move from a "design-to-production" mindset, with predetermined endpoints, to a "designing continuously" mindset, in which adaptive problem-solving and iterative refinement are prioritized throughout the project lifecycle (Couch & Lu, 2024).

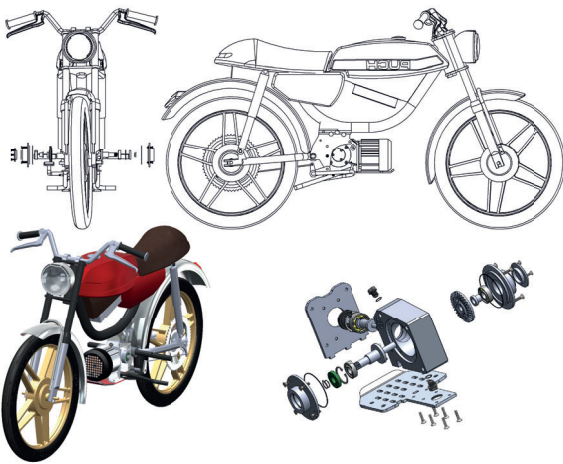
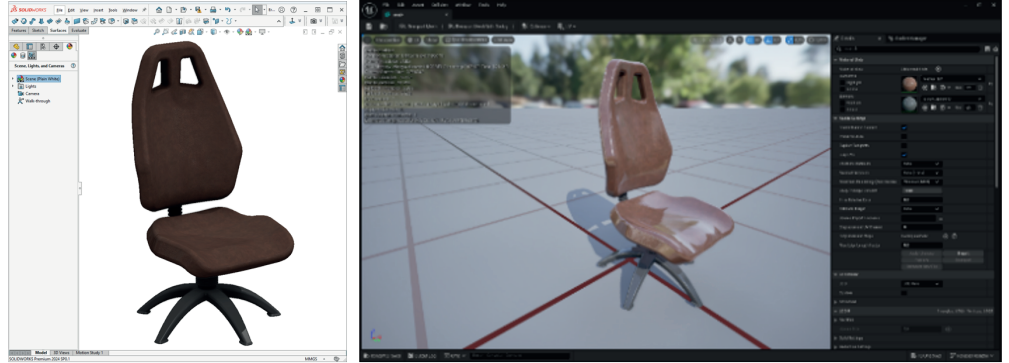


Figure 4: Gearbox design for moped electric conversion on CAD with simulation of assembly, 3D printed prototype (top right), and actual final product manufactured in CNC (Author's 3D model and project).

Figure 5: 3D model transfer from CAD software to Unreal Engine for evaluation, refinement of materials and physical properties (Author's 3D model).



3.3 Interdisciplinary Hybridity: The Designer-Maker-Engineer

The author's professional identity has evolved into that of a "designer-maker-engineer" (see Section 2.5) -a hybrid role that combines aesthetic sensibility with fluency in CAD software, generative design algorithms, materials science, and machine operation (Sealy et al., 2018).

This convergence is visible in the CAD-to-Unreal Engine workflow embedded within the tug and gearbox projects' additive manufacturing pipelines -not a separate physical case, but a digital evaluation stage integrated into both AM-fabricated projects described in Sections 3.1 and 3.2. Within this workflow, material selection is no longer treated as a final aesthetic decision but as a data-driven step: material behavior and physical properties are evaluated digitally -drawing on the kind of surface-roughness and kerf-width data discussed in Section 2.4- before any physical print is produced (Liu et al., 2024). Figure 5 illustrates this workflow: the 3D model is transferred from CAD software into Unreal Engine, where material properties and physical behavior are evaluated and refined in a high-fidelity digital environment before any fabrication commitment is made -a process that embodies the data-driven, integrative reasoning central to the designer-maker-engineer role. The material and geometric parameters validated in this digital simulation -confirmed wall thicknesses, support requirements, and material selection- are then carried forward directly as the print settings used in the physical AM production of the tugboat and gearbox models described in Sections 3.1 and 3.2,

closing the loop between digital evaluation and physical additive manufacture. The workflow discussed in this section is therefore best understood not as a third, independent production case, but as the digital-to-physical decision layer shared by the two physical cases already presented.

Operating in this hybrid role involves constant negotiation between creative intuition and technical constraint. Parameters such as layer adhesion, support structure design, and the post-processing behavior of printed polymers regularly impose limits on initial design intentions, requiring the designer to revise form, geometry, or material choice in response to manufacturability feedback. This negotiation is not experienced as a loss of creative control, but as an extension of the design process into territory previously delegated to engineers or production specialists.

While the case studies discussed here are drawn from maritime and mechanical engineering contexts, the underlying pattern -direct designer engagement with fabrication parameters, recursive design-fabrication loops, and a hybridized skill set- is not inherently specific to these domains. Section 5 returns to this point in considering how the dynamics identified here might apply to, or differ in, other design fields such as architecture, biomedical design, or consumer product design.

3.4 Cross-Case Comparison

To make the comparison across the two physical cases and the shared digital workflow more systematic, and to summarize how each supports the three

dynamics discussed above, Table 1 presents the cases against the same analytic criteria: purpose, fabrication method, the critical design decision involved, the AM-enabled change each case illustrates, and its outcome.

4 Methodology

This study employs analytical autoethnography (Anderson, 2006) as its core methodology, treating the author's own professional and pedagogical experience as the primary site of inquiry. This approach is positioned as a deliberate methodological choice for studying cultural and epistemic change in design practice -phenomena that are not easily captured through participant-based observation or interview-based methods alone, since they concern shifts in the researcher's own professional identity, reasoning, and ways of working.

4.1 Rationale for an Autoethnographic Approach

Autoethnography was selected because it allows for direct access to "situated knowledge" and the sensory feedback loops that are central to AM-integrated design practice (Cordeiro-Nilsson & Hawamdeh, 2011). Other qualitative approaches -such as interview-based studies with practitioners, or ethnographic observation of design teams- could capture some of these dynamics from an external viewpoint, but would not provide the same depth of access to the tacit, embodied decision-making that occurs during hands-on fabrication. By positioning the author as both subject and instrument, the study foregrounds the material and social dimensions of design work and the role of tools and materials in shaping creative reasoning (Self, 2012). Figure 6 provides an overview of the research design, illustrating how the three data sources feed into the analytical autoethnographic process, how the resulting themes are grounded in the case studies, and how member checking and the theoretical framework together support the credibility and transferability of the findings.

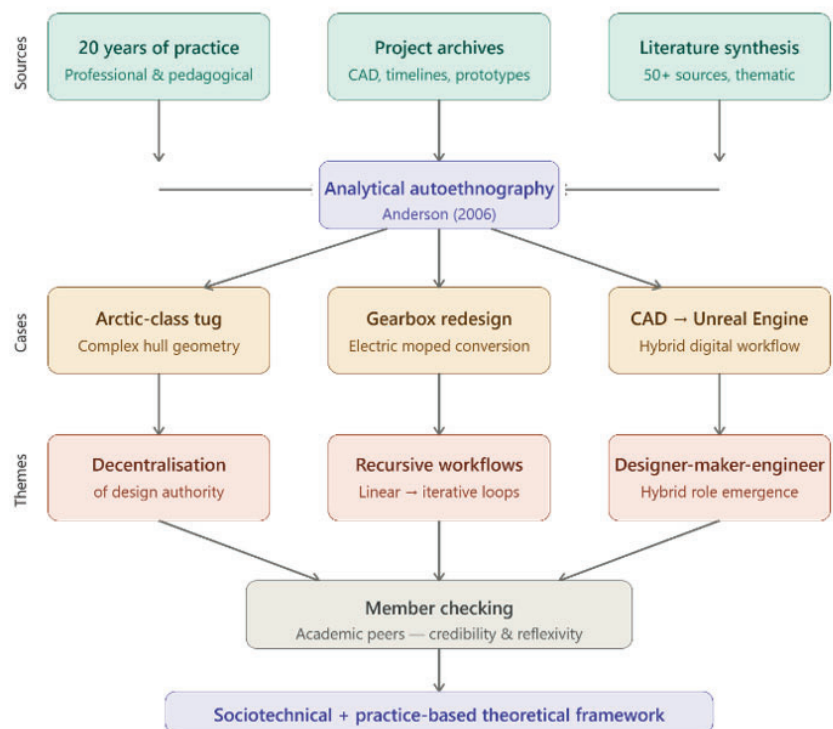
Analytically, the three dynamics reported in Section 3 arrived at through a staged

Dimension	Comparison across the three cases
Purpose	Tugboat: fabricate a complex hull without external tooling Gearbox: redesign a gearbox assembly for electric conversion CAD→Engine: validate print-ready material properties for Tugboat & Gearbox
Fabrication method	Tugboat: direct AM production of complex hull geometry Gearbox: AM prototyping integrated with CNC final manufacture CAD→Engine: not a separate pathway; feeds print parameters to Tugboat & Gearbox
Critical design decision	Tugboat: retaining fine structural detail without a mold Gearbox: merging design and fabrication into overlapping cycles CAD→Engine: treating material behavior as data before printing
AM-enabled change (dynamic)	Tugboat: decentralization of design authority (Sec. 3.1) Gearbox: linear-to-recursive workflow reconfiguration (Sec. 3.2) CAD→Engine: designer-maker-engineer role emergence (Sec. 3.3)
Outcome	Tugboat: full fabrication control; closer client relationship Gearbox: self-reported, substantial dev.-time reduction (qualitative; see Sec. 5.3) CAD→Engine: material choices validated digitally before commitment

Table 1: Systematic comparison of the two physical case studies and the shared CAD & Unreal Engine workflow across the same analytic criteria.

process rather than asserted directly from experience. First, discrete, dateable events drawn from the project archives -a fabrication decision, a workflow substitution, a renegotiation of a role or responsibility- were extracted from CAD iteration logs, project notes, and timelines and given short descriptive labels (open

Figure 6: Overview of the research design (Author's diagram).



coding). Second, these labels were grouped into candidate clusters wherever they described the same kind of shift recurring across more than one project (*axial grouping*); clusters that applied to only one project, or that could not be traced to a specific documented event, were set aside. Third, the remaining clusters were checked against the thematic-synthesis literature reviewed in Section 4.2 (Thomas & Harden, 2008), retaining only those that were both empirically recurrent in the archive and conceptually distinct from one another. This iterative comparison converged on the three dynamics presented in Section 3; the member-checking process described in Section 4.4 was then used to test whether these labels matched how colleagues familiar with the work independently described the same shifts.

4.2 Literature Synthesis and Source Selection

To situate the reflexive analysis within existing scholarship, a thematic synthesis (Thomas & Harden, 2008) of over fifty academic and professional sources was conducted. Sources were identified through targeted searches in academic databases using terms related to additive manufacturing, industrial design workflows, design epistemology, and hybrid fabrication. Inclusion was limited to publications addressing the intersection of AM with industrial design workflows, professional roles, or design epistemology. Sources focused exclusively on the mechanical properties of materials, or on engineering applications without implications for the design process, were excluded. This synthesis directly informed the three dynamics examined in Section 3 and provided the technical literature on laser cutting optimization, surface roughness prediction, and post-processing of printed polymers, discussed in Section 2.4.

4.3 Data: Project Archives and Development Records

The empirical material for this study consists of project archives accumulated over twenty years of practice, with particular focus on two physical case

projects that exemplify the transition from linear to recursive workflows -the Arctic-class tugboat and the electric moped gearbox conversion- together with the CAD-to-Unreal Engine digital workflow that was integrated into both projects' additive manufacturing pipelines and is analyzed separately in Section 3.3. These archives include CAD files, iteration histories, printed prototypes, and project timelines recorded contemporaneously during each project.

These two physical projects, and the CAD-to-Unreal Engine workflow embedded within them, were selected from the twenty-year archive using three explicit criteria: (1) the two physical cases employ distinct fabrication pathways -direct AM production for the tugboat and an AM-CNC hybrid for the gearbox- maximizing variation in how AM was integrated into physical production, while the shared CAD-to-Unreal Engine workflow was included because it directly determines the material and print parameters subsequently used in fabricating both, making it a necessary part of either case rather than an independent third pathway; (2) each is documented by a complete project record - CAD iteration history, printed or machined artifacts, and a contemporaneous project timeline - sufficient to support the analysis in Section 3; and (3) together they foreground all three dynamics introduced in Section 1 with particular clarity, allowing the dynamics to be illustrated with concrete, traceable evidence rather than asserted in the abstract. Projects lacking complete and recent records, or predating the author's consistent practice of retaining CAD iteration histories, were not considered for inclusion.

Table 2 summarizes this selection logic directly: which role each case plays, which of the three dynamics from Section 1 it is used to illustrate, and why it was chosen over other candidate projects in the archive.

The development-time change reported qualitatively in Section 3.2 was assessed by comparing the documented timelines of these AM-integrated projects against the author's own records of comparable projects

completed earlier in his career using linear, outsourced workflows. This comparison is based on a single practitioner's records across a small number of projects and was not conducted under controlled or independently verifiable conditions -project scope, client requirements, and team composition varied across the projects compared. For this reason, the change is reported only as a qualitative, personally observed trend rather than as a specific percentage, so as not to imply a level of measurement precision the underlying data cannot support.

Visual materials (*Figures 1-5*) are drawn from these same archives. As author-created materials, they are treated not as neutral illustrations but as primary data: artifacts that embody the tacit knowledge generated through the making process (*Diegel et al., 2019*) described in Section 2.2.

4.4 Reflexivity and Credibility

Given that the primary data derive from a single practitioner's experience, reflexivity is treated as a core component of the research design rather than a supplementary consideration (*Jamieson et al., 2023*). Throughout the analysis, the author sought to distinguish between observations grounded in documented project records (*timelines, CAD iterations, physical prototypes*) and interpretive claims about their broader significance, with the latter explicitly flagged as reflexive interpretation rather than empirical finding.

To support the credibility of these interpretations, and without extending the study's single-practitioner scope, preliminary themes and reflexive accounts were shared through informal conversations, rather than a structured written instrument, with a small number of academic colleagues -at the associate professor and professor rank, met at academic symposia in Turkey and abroad- and with two to three former research assistants who had since graduated and moved to positions at other universities, all of whom were familiar with the author's practice. These individuals were not treated as research participants or additional data sources; rather, they were asked to comment

Case	Role	Dynamic Illustrated	Why Selected
Tugboat	Physical (direct AM)	Decentralization of design authority (3.1)	Complex hull geometry required full designer control over print parameters with no external tooling
Gearbox	Physical (AM-CNC hybrid)	Linear-to-recursive workflow reconfiguration (3.2)	Electric conversion required repeated redesign cycles impossible under the prior linear, outsourced workflow
CAD→Unreal	Digital layer	Designer-maker-engineer role emergence (3.3)	Directly determines the material/print
	(embedded in both)		parameters used in both physical cases; not an independent pathway

Table 2: Case-selection logic: role, illustrated dynamic, and selection rationale for each case.

on whether the described shifts in workflow and professional role corresponded to their own observations of the author's work over time. This process functioned as a form of member checking (*Motulsky, 2021*), intended to surface alternative interpretations or counter-examples rather than to produce statistical agreement, and does not alter the single-practitioner basis of the study's empirical data. Because these exchanges were informal and did not constitute data collection from human subjects, no record of participants' exact number, dates, or demographic details was retained, consistent with their role as reflexive sounding-boards rather than research participants (*see Ethical Statement*).

While this constrains the generalizability of its findings -a limitation discussed further in Section 5- the intent of this methodology is not to produce findings that generalize statistically across practitioners, but to

provide a detailed, theoretically grounded account of one practitioner's transition that can inform -and be tested against- future studies involving multiple practitioners or design teams.

5 Discussion

5.1 Repositioning AM within Sociotechnical and Practice-Based Theory

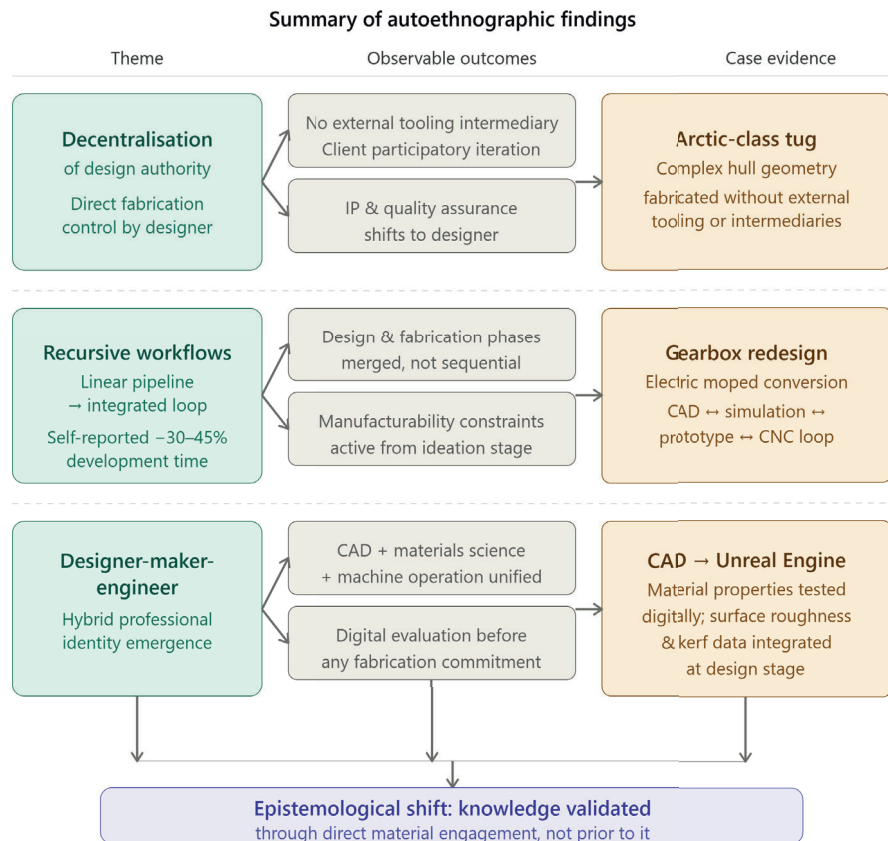
The three dynamics identified in Section 3 (*decentralization of design authority, the shift from linear to recursive workflows, and the emergence of the designer-maker-engineer*) can be read as concrete manifestations of the theoretical framework outlined in Section 2.6. From a sociotechnical perspective, these dynamics illustrate how a change in tooling (*AM*) reconfigures not only technical procedures but also the network of relationships between designer, client, and manufacturer, through which design decisions are made and authorized (Bogers et al., 2015). From a practice-based perspective, the recursive workflows and hybrid skill set described in

Section 3 exemplify how design knowledge is generated through, rather than before, material engagement.

In this study, "epistemological shift" refers specifically to a change in where and how design knowledge is validated: from a model in which knowledge is encoded primarily in drawings and specifications, validated through review and approval processes external to the designer, to one in which knowledge is continuously tested and revised through direct material feedback within the designer's own recursive loop. This is not presented as a claim that AM changes the nature of knowledge in general, but as a description of a specific, observable change in the practitioner's own workflow and validation practices.

Figure 7 summarizes the three analytical themes identified in Section 3, along with their observable outcomes and supporting case evidence, and illustrates how they converge on the epistemological shift

Figure 7: Summary of autoethnographic findings across the three analytical themes (Author's diagram).



central to this study's contribution.

5.2 Transferability Beyond Industrial Design

While the case studies in Section 3 are drawn from maritime and mechanical engineering contexts within industrial design, the underlying pattern they illustrate -direct designer engagement with fabrication parameters, recursive design-fabrication loops, and a hybridized skill set- plausibly extends to adjacent fields. In architecture, AM-enabled prototyping of complex facade or structural components could similarly narrow the gap between design intent and construction feasibility, fostering a "designer-maker-engineer" hybridity among architects who engage directly with fabrication technologies. In biomedical design, the direct fabrication of patient-specific devices or anatomical models creates analogous pressures toward decentralized, iterative workflows, though with additional regulatory constraints not present in the cases discussed here. In consumer product design, smaller-batch, customization-oriented production may similarly favor recursive over linear workflows.

These extensions are offered as plausible directions for future research rather than as findings of this study. The transferability of the dynamics identified here should be understood as conceptual rather than empirical: the patterns observed may recur in other domains, but their specific manifestations -and the constraints shaping

them- would need to be examined through domain-specific studies. As illustrated in Figure 8, the three dynamics share a common structural logic across domains, while the specific constraints shaping their expression -regulatory frameworks in biomedical design, construction codes in architecture, and scale considerations in consumer product design- vary significantly, underscoring the need for domain-specific empirical follow-up.

5.3 Limitations and Generalizability

As a single-practitioner autoethnography, this study's findings are not intended to be statistically generalizable across the broader population of industrial designers. The development-time reduction reported qualitatively in Section 3.2, in particular, reflects one practitioner's experience across a limited set of projects and should not be read as a benchmark applicable to other practitioners, teams, or organizational contexts, which may face different constraints related to scale, client expectations, or available fabrication technologies.

To state this limitation as precisely as possible: the development-time comparison is drawn from the author's own timeline records for two AM-integrated projects (*the tugboat and the gearbox*) set against his records of a small number of comparable earlier projects completed under linear, outsourced workflows. It is not an average computed across the full twenty-year archive and has not been independently audited. For

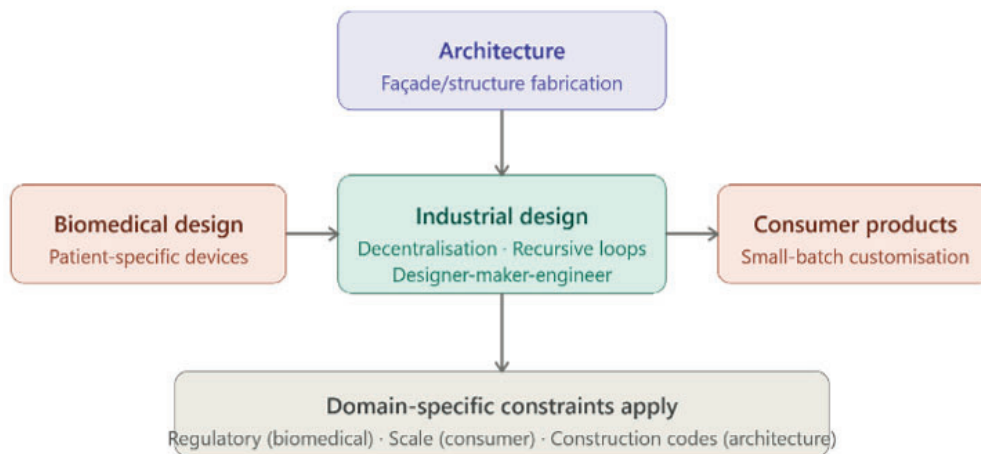


Figure 8: Conceptual transferability of the study's findings to adjacent design fields (Author's diagram).

this reason, the article deliberately reports the change as a qualitative, practitioner-observed trend rather than as a percentage or numerical range: doing so would suggest a level of measurement control -consistent project scope, matched team composition, independent verification- that this single-practitioner comparison does not have. No quantitative claim should be drawn from this comparison beyond the qualitative shift discussed in Section 3.2.

Instead, the study's contribution lies in its transferability: the detailed, contextualized account of one practitioner's transition provides a framework of concepts -decentralization, recursive loops, designer-maker-engineer- that other researchers and practitioners can use to examine their own experiences, and that future studies involving multiple practitioners could test more systematically. The member-checking process described in Section 4.4, while not a substitute for multi-practitioner data, provides some indication that the described shifts are recognizable beyond the author's own self-perception.

5.4 The Tension Between Creative Freedom and Manufacturability

A recurring thread across the dynamics discussed in Section 3 is the tension between creative freedom and manufacturability. AM is often associated with expanded design freedom, allowing geometries and customizations that would be difficult or costly in conventional manufacturing. However, the technical literature reviewed in Section 2.4 demonstrates that this freedom is bounded by concrete constraints: print orientation,

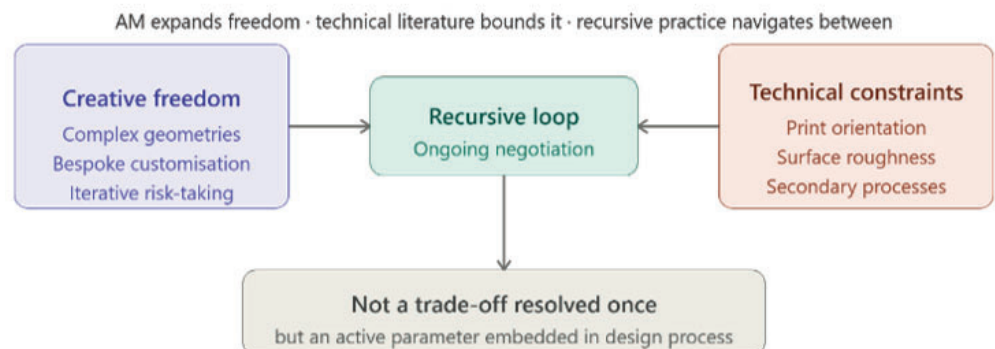
infill parameters, and material choice all interact with secondary processes such as laser cutting in ways that affect surface quality and dimensional accuracy. The tension between creative freedom and manufacturability is further complicated by AI-driven tools. Recent research indicates that while generative design enhances visual appeal and user experience, it often prioritizes aesthetics over practicality, necessitating a 'human-in-the-loop' refinement to align with real-world manufacturing constraints (Özsoy, 2025).

For the designer-maker-engineer, this means that manufacturability constraints are not external limitations imposed after design decisions are made, but active parameters that must be considered throughout the design process. The recursive workflows described in Section 3.2 are, in part, a response to this reality: by integrating fabrication and testing into the design loop, the designer can identify and resolve manufacturability conflicts iteratively, rather than encountering them as late-stage failures. Figure 9 maps this dynamic: creative freedom and technical constraints function as opposing forces, with the recursive loop serving as the active resolution mechanism, not a one-time trade-off, but an ongoing negotiation embedded in the design process itself.

6 Conclusion

This study has examined, through an analytical autoethnographic lens, how additive manufacturing (AM) functions as a catalyst for workflow and identity transformation in industrial design practice. Drawing on twenty years of professional

Figure 9: Creative freedom and manufacturability as opposing forces in AM-integrated practice, mediated by the recursive design loop (Author's diagram).



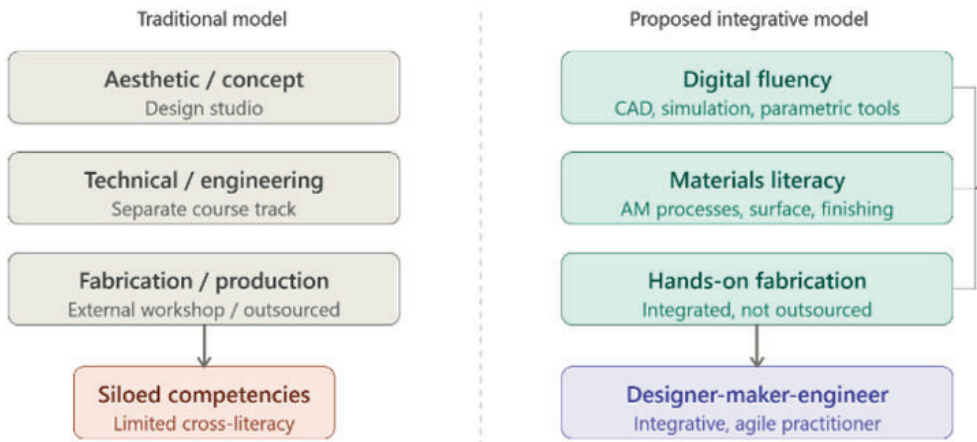


Figure 10: Traditional compartmentalized curriculum contrasted with the proposed integrative model for design education (Author's diagram).

and pedagogical experience, the analysis identified three interrelated dynamics: the decentralization of design authority, the reconfiguration of linear workflows into recursive loops, and the emergence of the hybrid “designer-maker-engineer.”

Together, these dynamics point to a broader epistemological shift: design knowledge is increasingly validated through direct material engagement and iterative making, rather than solely through pre-fabrication review and approval. As discussed in Section 5, this shift is defined by real technical constraints -particularly in secondary processes such as laser cutting and surface finishing- that require designers to treat manufacturability as an integral part of the creative process rather than a downstream concern.

As a single-practitioner autoethnography, this study does not claim statistical generalizability; rather, it offers a conceptually transferable account that future research, particularly studies involving multiple practitioners across different domains such as architecture, biomedical design, or consumer product design, can build upon and test.

These findings carry implications for design education. If the designer-maker-engineer is becoming a professional reality rather than an exception, curricula should move away from compartmentalized skill silos toward integrative, hands-on pedagogical models that combine digital fluency, materials literacy, and direct fabrication experience.

As Figure 10 illustrates, the shift required is not merely additive -adding new courses to an existing structure- but structural: the three competency areas must be taught as an integrated whole rather than as parallel, non-communicating tracks.

Future work could examine how such integrative models affect student outcomes, and how the dynamics identified here interact with emerging concerns such as user co-creation, distributed manufacturing, and the sustainability of AM-based production on a large scale.

Credit authorship contribution statement

The author did conceptualization, formal analysis, investigation, methodology, project administration, resources, software, visualization, writing of the original draft, review, and editing.

Conflict of interest

The author declares that there are no conflicts of interest

Ethical statement

The author declares that ethical committee approval is not required for this study. As a practice-based analytical autoethnography, the research is based on the author's own professional experience and project archives. Academic colleagues consulted informally for member checking (*Section 4.4*) were not treated as research participants or data sources, and no personal, identifying, or demographic information about them was collected or retained.

Declaration of generative artificial intelligence (AI) and AI-assisted technologies in the writing process

In the preparation of this manuscript, the author utilized Claude-AI and Grammarly for language and readability enhancement and employed NotebookLM to verify compliance with the writing guidelines. Following the use of these tools, the author reviewed and edited the content as necessary and assumes full responsibility for the integrity of the final publication.

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