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Teamflow in product development teams: designing resilient engineering environments

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ABSTRACT: This paper presents a controlled laboratory study investigating how environmental factors influence team resilience and teamflow in product development contexts. It examines which factors shape teams' adaptive responses and collective engagement. In the study, one factor per People–Organization–Technology dimension was systematically manipulated: member unavailability, time autonomy, and material quality. Results reveal distinct effects on performance and collaborative dynamics, providing empirical foundations for designing resilient team environments in engineering work.

KEYWORDS: teamwork, collaborative design, socio-technical systems, teamflow, team resilience

1. Introduction

In the final integration phase of a cyber-physical system, even minor perturbations can cascade rapidly: a domain expert becomes unavailable, supplier specifications shift late, or toolchains fail at critical handoffs. In such situations, teams that sustain a shared understanding of goals and constraints, redistribute responsibilities without friction, and retain constructive communication under load tend to stabilize outcomes rather than derail them (Kozlowski and Ilgen, 2006). However, research on new-product development shows that disruptions and failure-inducing factors may emerge at any stage of the development process, underscoring the relevance of team resilience across the entire product development lifecycle (Cooper, 2019). This pattern, in which teams convert stressors into adaptive coordination, is increasingly pivotal as product development is shaped by digitalization, rising stakeholder density, tool fragmentation, and accelerated decision cycles (Ritzer, Naik, et al., 2025). Engineers operate under conditions that simultaneously increase complexity and compress decision windows, placing heightened demands on collaboration structures, autonomy, and role clarity (Dumitrescu et al., 2021; Grote et al., 2020). Contemporary accounts of engineering work emphasize the centrality of the engineer within socio-technical environments and argue for human-centered, flexible, and digitally enabled settings that align methods, processes, tools, and organization to the realities of modern development (Albers et al., 2019; Teichert et al., 2023). Latest studies on current trends in engineering environment indicate growing team sizes and diversity, more stakeholders, shifting responsibilities, and conflicts arising from mismatched methods and development speeds - conditions that elevate the need for resilience at the team level and for environments that enable individuality without sacrificing performance (Ritzer, Dernbach, et al., 2025).

Yet, despite a broad consensus on the importance of people-organization-technology alignment, there remains a practical gap: organizations lack mechanism-focused, evidence-informed guidance on which internally influenceable aspects of the engineering environment most reliably support resilient team dynamics and how such resilience relates to collective performance states such as teamflow. Teamflow theory provides the psychological foundation for understanding collective engagement, while socio-technical systems theory explains how environmental structures enable or constrain such states. Building on these perspectives, we conceptualize team resilience as the proximal mechanism linking the engineering environment to teamflow: environments that support adaptation and recovery under change increase the likelihood that teams sustain the collective performance state of teamflow, providing a basis for deriving actionable, evidence-based guidance for the design of engineering environments.

2. State of research

2.1. Teamflow in product development: definition, conditions, and relevance

Teamflow is a collectively experienced, high-engagement state in which a team coordinates seamlessly, sustains shared attentional focus, and perceives joint progress toward clear goals. At its foundation, flow theory conceptualizes optimal experience as the alignment of challenge and skill (Csikszentmihalyi, 1975) supported by clear goals, immediate feedback, perceived control, and intrinsic motivation (Peifer et al., 2021). While flow cannot be directly induced, it can occur when the necessary conditions are present. These conditions can be created intentionally to increase the likelihood of flow experiences (Csikszentmihalyi, 1990). Teamflow extends this person-level construct to the social level: the team's attention and actions synchronize, coordination losses diminish, and collective progress becomes salient. Van den Hout et al. (2019) formalize teamflow as shared flow during interdependent tasks and identifies the social-cognitive features that typify it: sense of unity, joint progress, mutual trust, and holistic focus. These align with well-established teamwork enablers (clear goals, enabling structure, supportive context) and with socio-technical views that place engineers at the center of product development (Albers et al., 2019). The Team Flow Monitor (TFM) captures teamflow and its antecedents, showing associations with trust, communication, and shared goals (van den Hout et al., 2019). A longitudinal intervention across 15 teams reported medium improvements in teamflow and positive effects on team dynamics and performance (van den Hout et al., 2024). Shared leadership and jointly set interim feedback have been shown to foster teamflow in both agile and classical project settings (Aubé et al., 2017; Heyne et al., 2011). Psychological and neuroscientific evidence further implicates communication quality, shared mental models, and inter-brain synchronization as correlates of teamflow (Aust et al., 2023; Shehata et al., 2021). Teamflow is distinct from individual flow: deep personal absorption alone does not ensure coherent system-level progress. Teamflow requires emergent coordination so that contributions align and integration cycles shorten. Under rising stakeholder density and tool/method fragmentation, teams that maintain goal coherence, fluid role adaptation, and constructive communication are more likely to sustain the conditions for teamflow, with downstream benefits for throughput, decision speed, and innovation (Peifer et al., 2021; van den Hout et al., 2024). In sum, teamflow in product development is a collective performance state contingent on social and organizational alignment of challenge–skill balance, goal/feedback clarity, trust, and joint focus. Because these antecedents are proximal to resilience, they provide a theoretically grounded bridge to our mechanism linking the engineering environment, measurement of resilience, and the emergence of teamflow.

2.2. Resilience as an enabler of teamflow

The presented flow-enabling conditions, like high levels of trust, focus, and adaptive coordination, are fragile in volatile environments, where unexpected disruptions can fragment attention, delay decisions, and erode psychological safety. In such contexts, team resilience becomes essential: it allows teams to withstand perturbation while preserving or restoring the collective states required for teamflow. Without this stabilizing capacity, flow remains a fragile and short-lived phenomenon. Scientifically, team resilience refers to a team's collective capacity to anticipate potential disruptions, absorb immediate shocks, adapt strategies in real time, and recover functioning after adverse events (Alliger et al., 2015; Stoverink et al., 2020). Unlike individual resilience, which emphasizes personal coping and self-regulation, team resilience emerges from shared beliefs, joint routines, and coordinated responses that protect collaboration quality and system-level coherence (Gucciardi et al., 2018). It includes behaviors such as distributed problem solving, real-time strategy shifts, mutual support, and learning from failure (Maynard et al., 2020). These processes help teams sustain the core antecedents of flow, shared goals, mutual trust, and focused attention, when facing uncertainty or overload. Because teamflow is difficult to measure directly in short-cycle lab settings, this study uses team resilience as a theoretically grounded proxy. Validated resilience instruments capture the behavioral and cognitive capacities that underlie flow emergence. In particular, Sharma and Sharma (2016) multidimensional resilience scale includes social capital, collective efficacy, and structural adaptability, dimensions that strongly relate to flow-enabling mechanisms. Thus, measuring team resilience allows us to assess a team's likelihood of maintaining or regaining flow in the face of environmental stressors. In this way, resilience acts not only as a prerequisite for teamflow but also as a measurable indicator of a team's flow potential under pressure.

2.3. Factors of engineering environments influencing teamflow

Engineering environments in product development can be conceptualized as company-internal, designable conditions across people, organization, and technology that shape day-to-day engineering work as a socio-technical system (VDI e. V., 2019). Prior work shows that developers operate at the intersection of methods, processes, tools, and organization, and that their effectiveness depends on this alignment (Ehrlenspiel & Meerkamm, 2017; Albers et al., 2019). Recent trend analyses for engineering environments highlight increasing team size and diversity, stakeholder density, and fragmented toolchains, which raise demands on collaboration structures and role clarity (Dumitrescu et al., 2021; Ritzer, Dernbach, et al., 2025; Ritzer, Naik, et al., 2025). People- and organization-related factors are closely connected to antecedents of teamflow. Empirical studies on New Work and modern collaboration identify leadership behavior, culture and climate, participation, learning and feedback practices, autonomy, and structural clarity as key drivers of motivation, sustainable decisions, informal learning, and innovative behaviour (Teichert et al., 2023). In engineering-specific contexts, advanced systems engineering and digital collaboration studies emphasize that clearly defined roles, coordination routines, and supportive project climates are required to cope with increasing complexity and time pressure (Dumitrescu et al., 2021; Balder et al., 2024; Müller et al., 2012). These conditions are theoretically aligned with teamflow prerequisites, yet they are typically linked to performance, innovation, or well-being, not explicitly to teamflow. Technological factors further shape the likelihood of teamflow: tool interoperability, access to suitable materials and test infrastructure, and usable, reliable collaboration systems influence coordination effort, learning opportunities, and perceived control.

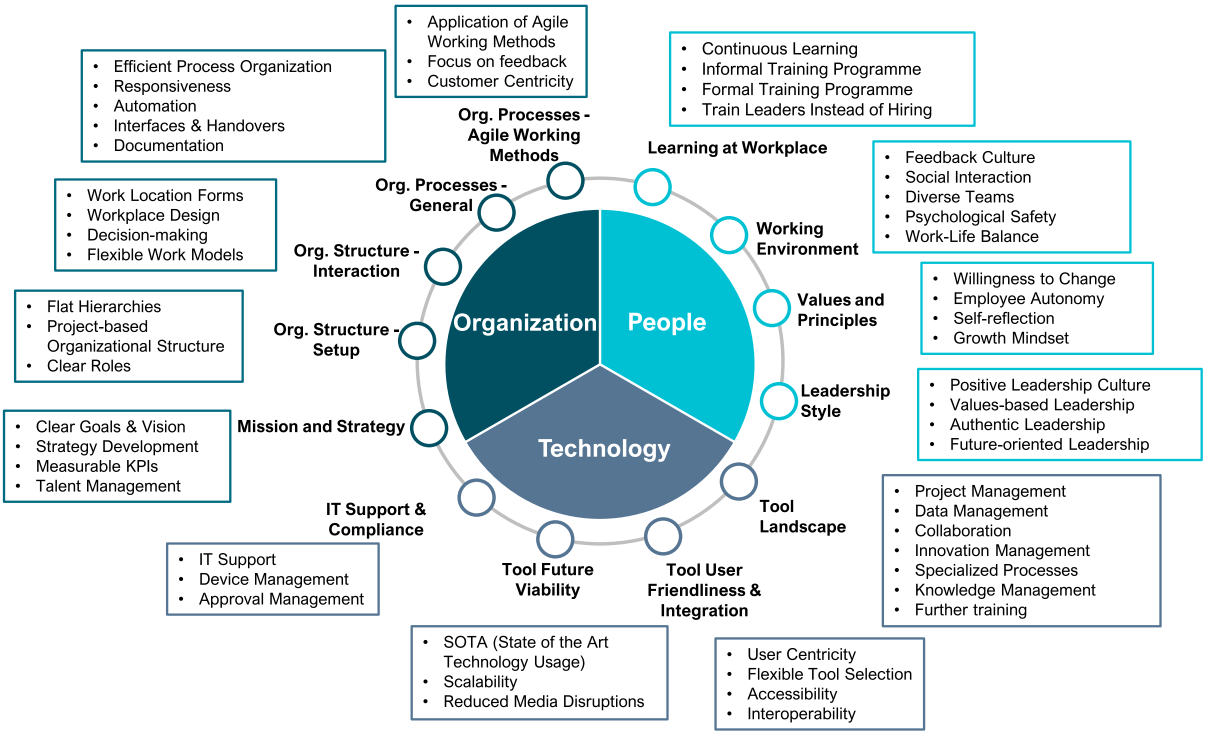


Figure 1. Elements of an engineering environment based on Ritzer, Naik, et al. (2025)

Systematic evaluations of "new ways of working" in engineering indicate that these factors affecting how teams handle interruptions, uncertainty, and phase transitions in development tasks (Ritzer, Mithani, et al., 2025). Building on the understanding by Ritzer, Dernbach, et al (2025) that a product development environment is a socio-technical system comprising all contextual factors an organization can influence, structured along People, Organization, and Technology, Ritzer, Naik, et al. (2025) summarized the elements of an engineering environment (cf. Figure 1), providing the basis for validating factors that influence teamflow.

3. Research goal, questions, and contribution

This study explains and empirically examines how engineering environments, conceptualized as a socio-technical system across people, organization, and technology (P–O–T), influence team-level resilience and the emergence of teamflow in product development teams, and derives actionable guidance for environment design. We test the mechanism environment → team resilience → teamflow, using resilience as the measurable, proximal condition through which environment factors influence collective performance states. The study addresses three research questions. RQ1 and RQ2 establish the methodological foundation for testing the proposed mechanism, while RQ3 provides the core empirical contribution.

- RQ1: How can the engineering environment be operationalized as a socio-technical system (technology, organization, people) to validly measure factors relevant to teamflow?
- RQ2: How can a controlled laboratory study be designed to manipulate three exemplar environmental factors and to obtain valid insights into team resilience and teamflow?
- RQ3: What are the effects of the manipulated environmental factors on team resilience and, in turn, on teamflow under the tested laboratory conditions?

The contribution is threefold: (i) an operationalization of the engineering environment via a compact P–O–T questionnaire (addressing RQ1), (ii) a controlled laboratory study design of the proposed mechanism using three exemplar factors (addressing RQ2), and (iii) evidence-based guidance for designing environments that increase the likelihood of team resilience and teamflow in product development (addressing RQ3).

4. Operationalizing the engineering environment as a questionnaire

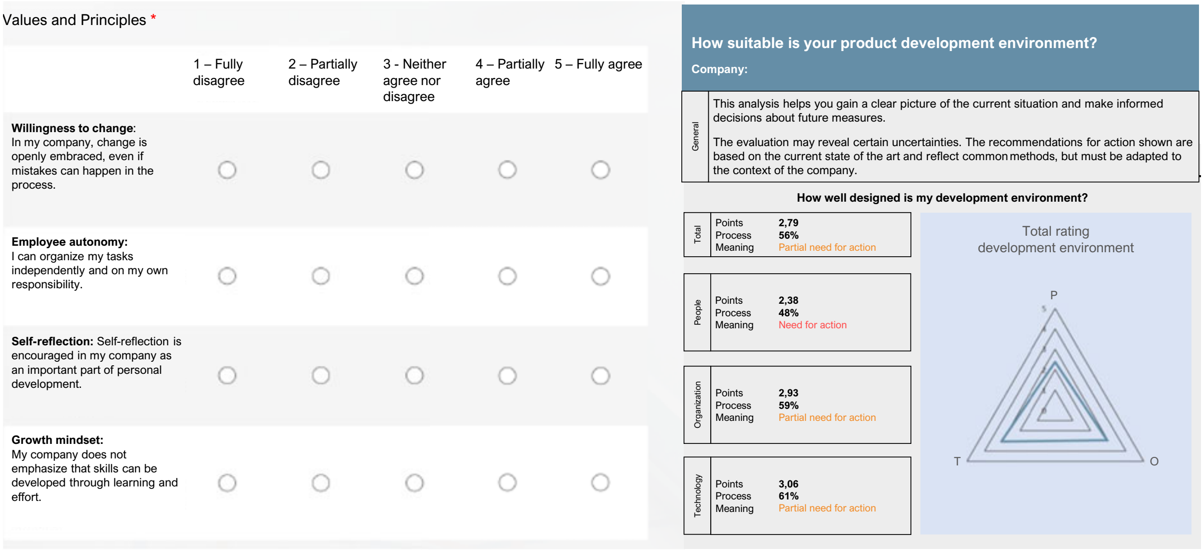
As the first step to address RQ1, we operationalized the engineering environment as company-internal, designable conditions across People, Organization, and Technology (P–O–T) and derived a compact questionnaire to assess these conditions at team level. The item pool was derived from the consolidated factors summarized in Section 2.3 based on Ritzer, Naik, et al. (2025). The questionnaire maps items to each dimension. Each dimension is decomposed into domains that describe the working environment in a way that is meaningful for teams and actionable for leaders:

- People domains capture the social and developmental climate (learning at workplace, working environment, values and principles and leadership style).
- Organization domains capture how work is structured and coordinated (organizational processes, organizational interaction, organizational setup, agile working methods, mission and strategy).
- Technology domains capture the digital/physical system landscape supporting engineering (tool landscape, tool user friendliness and integration, tool future viability, IT support and compliance).

Within each domain, concrete factors are operationalized as Likert-scaled items that can be rated on a 5-point Likert scale. Figure 2 left shows an excerpt from the domain “Values and principles”, e.g. factor willingness to change: In my company, change is openly embraced, even if mistakes can happen in the process.

To use the questionnaire, team leaders administer it to members and immediate stakeholders of a product development team, ideally sampling all roles within a comparable project phase and recording basic context (team size, phase, toolchain) to support interpretation.

To evaluate individual team results, item scores are averaged per P–O–T dimensions and aggregated to a composite environment index. An automated report presents dimension means with qualitative flags, a radar chart of the P–O–T profile, and targeted recommendations linked to low-scoring factors. Figure 2 right illustrates an exemplary report start page. Interpretation thresholds are ≥ 3.5 (good), $2.5 - 3.5$ (average), and < 2.5 (deficit), enabling before/after comparisons and benchmarking across teams or phases to guide targeted interventions on designable conditions.



Values and Principles *

	1 – Fully disagree	2 – Partially disagree	3 - Neither agree nor disagree	4 – Partially agree	5 – Fully agree
Willingness to change: In my company, change is openly embraced, even if mistakes can happen in the process.	○	○	○	○	○
Employee autonomy: I can organize my tasks independently and on my own responsibility.	○	○	○	○	○
Self-reflection: Self-reflection is encouraged in my company as an important part of personal development.	○	○	○	○	○
Growth mindset: My company does not emphasize that skills can be developed through learning and effort.	○	○	○	○	○

How suitable is your product development environment?

Company:

General

This analysis helps you gain a clear picture of the current situation and make informed decisions about future measures.

The evaluation may reveal certain uncertainties. The recommendations for action shown are based on the current state of the art and reflect common methods, but must be adapted to the context of the company.

How well designed is my development environment?

Total	Points Process Meaning	**2,79** **56%** Partial need for action
People	Points Process Meaning	**2,38** **48%** Need for action
Organization	Points Process Meaning	**2,93** **59%** Partial need for action
Technology	Points Process Meaning	**3,06** **61%** Partial need for action

Figure 2. Questionnaire excerpt from the domain “Values and principles” (left), exemplary report start page (right)

To validate the questionnaire and its report as an RQ1-aligned operationalization of the engineering environment, we conducted a two-stage validation focused on clarity, usefulness, and consistency.
Stage 1 (expert/practitioner review): Project leads and team members reviewed the questionnaire and report prototypes. Face validity (does the P–O–T profile reflect the observed environment), interpretability (scales, thresholds, visuals), and actionability (factor flags vs. known conditions) led to refinements: clearer threshold wording, explicit links between low dimension scores and underlying factors, and consolidation of overlapping items to reduce burden. This stage functioned as a pilot validation ensuring clarity and face validity before cross-context application.
Stage 2 (cross-context check): The instrument was applied in a single organization to test transferability across teams and phases and checked stability under repeated measurement. Profiles aligned with observed practices; known strengths/weaknesses surfaced consistently; and before/after comparisons showed sensitivity to local adjustments (e.g., phase-transition cadence, access to testing/data). The single-organisation setup ensured internal consistency and contextual control, while future work will extend validation across organisations with different resilience profiles to examine generalisability.
These results support RQ1: the engineering environment is validly operationalized as a socio-technical system (P–O–T) by a compact questionnaire whose aggregated report yields interpretable, team-level measures of designable factors relevant to conditions fostering resilience and teamflow.

5. Lab study design: testing three environmental factors on resilience

This chapter introduces a controlled laboratory study that systematically manipulates one environment factor per P–O–T dimension to jointly measures team resilience with validated items and initial teamflow indicators. The laboratory setting adopts the tower study by Kagan et al. (2018), as further developed by Batora et al. (2024). This setup allows precise manipulation of environmental conditions while assessing team resilience and teamflow in a context of high interdependence, clear goals, and immediate feedback. The laboratory study has been deliberately simplified and does not aspire to replicate the complexity of authentic product development in its entirety. Conversely, it focuses on key features of development work (e.g., goals, interdependence, resource constraints, and time pressure), thereby enabling a controlled examination of the underlying mechanisms. This stage is pivotal in enabling the transition to studies in more realistic settings.

5.1. Experimental setting and manipulated factors

The study examines how small teams adapt to realistic stressors by having them build the tallest possible structure that supports an uninterrupted stack of coins for at least three minutes, ideally surpassing a visible reference product. Dyadic teams are allotted 20 minutes to construct load-bearing towers using playing cards and paper clips. Each team completes two 20-minute iterations comprising a 5-minute ideation phase, sketching (paper and pencils) and inspection of the reference product to standardize baseline knowledge and reduce start-up variance - and a 15-minute implementation phase in which construction proceeds with the provided materials (10 playing cards, 10 paper clips, and 16 twenty-cent coins); teams may revise their concept at any time. Performance is primarily assessed by tower height and carried coins. Additional criteria include multi-dimensional assessment of team resilience (e.g., Sharma & Sharma, 2016) and structured observation by the study lead.

Environmental manipulations are applied exclusively in the first iteration to isolate their effects, while the second iteration is uniform and non-manipulated for all teams to enable within-team comparison. The design tests three targeted factors that reflect common coordination stressors in engineering work:

- Temporary member unavailability (People): One member leaves twice (2 min after 2 min; 4 min after 10 min), simulating interruptions and testing robustness to responsibility shifts and coordination losses.
- Time architecture and autonomy (Organization): Teams decide when to switch from ideation to implementation and may request materials freely, testing effects of self-determined pacing on collaboration and resilience.
- Material quality (Technology): Teams rebuild using a worn reference model with bent or torn cards, introducing instability and probing adaptive capacity under degraded resources.

A control condition mirrors the stable setting used for all iterations. Teams are evenly distributed across the four conditions (three teams each), ensuring balanced contrasts and identical task parameters. Across three runs, twelve teams ($n = 24$) complete both iterations, yielding a balanced dataset.

5.2. Measures and data collection

To link the manipulated environmental conditions in iteration 1 and the uniform baseline in iteration 2 to observable adaptation, we combine self-report, behavioral, and performance measures into a coherent, triangulated dataset. Immediately after each iteration, the participants complete a 12-item online questionnaire based on a Likert-scale from 0 (totally disagree) to 4 (totally agree) adapted from Sharma and Sharma (2016) to assess team resilience (cf. Table 1). The item pool covers coordination quality, adaptive adjustment, reflective analysis, role confidence, learning dissemination and error patterns. Behavioral data is collected via audiovisual recordings of all sessions. Items are coded so that higher values on items 1-9 indicate greater resilience, whereas items 10-12 are reverse coded. Participants are instructed to think aloud during the task. Transcription proceeds alongside structured logging of salient events, decision patterns, handover quality, and coordination behaviors. Lastly, performance is assessed by a score calculated as tower height multiplied by monetary value of coins divided by 3.

Table 1. Questionnaire items adapted from Sharma and Sharma (2016)

1	My team can work together in order to accomplish a goal
2	Team members effectively communicate with one another
3	We question each other when we think the work can be done better
4	Team members try to understand each other during work cooperation
5	Team members adjust their approach(es) to overcome obstacles
6	Differences between real and expected performance are critically and constructively analyzed
7	My team is just the right size to accomplish its purpose
8	I have confidence that my team members can perform tasks that are assigned to them
9	The lessons learned are made available to all the team members
10	The only way we can figure out how well we are performing is for other people to tell us
11	The same mistakes are made over and over again in the team
12	I felt stressed while working on this task

6. Resilient engineering environments to enable teamflow in product development teams

This chapter analyzes how teams adapted from the manipulated first iteration to the uniform second iteration, linking resilience ratings, stress, and performance with the specific people, organization and technology manipulation.

In the people group, teams improve both resilience and performance from iteration 1 to 2 (mean tower score rises from 29 to 38). Figure 3 shows increase on items linked to effective communication, adaptive adjustment, and reflective analysis, alongside declines on reverse-coded stress/fragility items, yielding an average resilience gain of +0.6. Behavioural notes indicate that anticipation of separation prompted explicit handover planning and timely information sharing, which reduced coordination losses when both members were present again and supported steadier implementation under time pressure. Stress declines by 0.8 points, and the group's successful recovery aligns with the preparedness induced by the initial interruption condition.

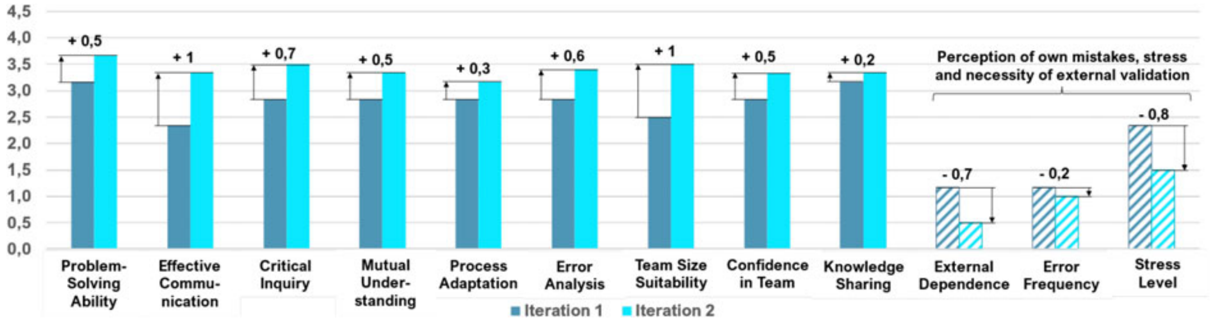


Figure 3. Average responses from the people group

In the organization group, performance rebounds strongly once external phase structure is restored (mean tower score rises from 12 to 35), and resilience rises by +0.4 on average. Figure 4 reflects improvements across collaboration and adjustment items, with concurrent reductions on reverse-coded indicators of coordination strain. The weak first-iteration score under self-determined switching is consistent with evidence that unstructured time allocation depresses performance (Kagan et al., 2018); in iteration 2, fixed timing enables clearer pacing, reduces switching costs, and lowers stress by 0.3 points. The large tower score delta illustrates sensitivity to phase control and the benefits of externally imposed cadence for short, high-intensity tasks.

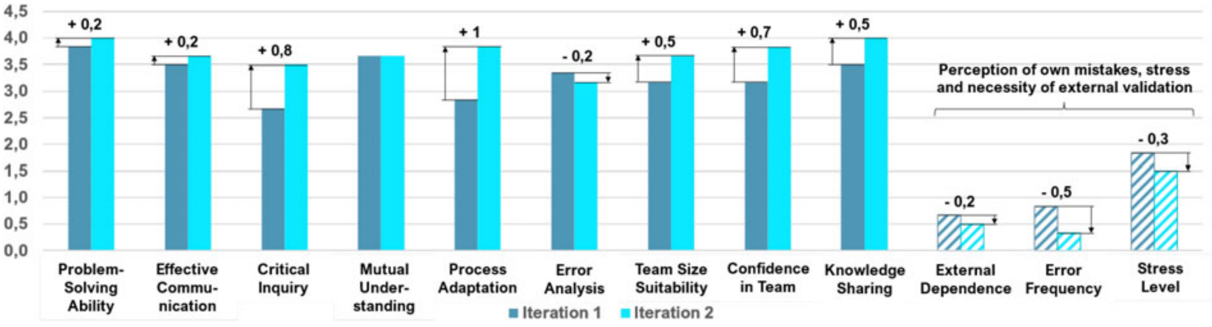


Figure 4. Average responses from the organization group

In the technology group, performance declines from iteration 1 to 2 (mean tower score reduces from 28 to 18) and average resilience dips slightly (−0.1). Figure 5 shows muted or negative changes on resilience items and increases on reverse-coded stress items (+0.5). Participants reported that in iteration 1 they leveraged folding lines in worn cards to accelerate construction; in iteration 2, building a new from fresh material was underestimated, leading to late-stage time pressure and less careful coin stacking. Observations confirm that timing misjudgements, not material quality per se, drove the deterioration. This condition highlights how a seemingly "better" tool context can introduce coordination and pacing burdens if teams fail to adapt strategies to changed affordances.

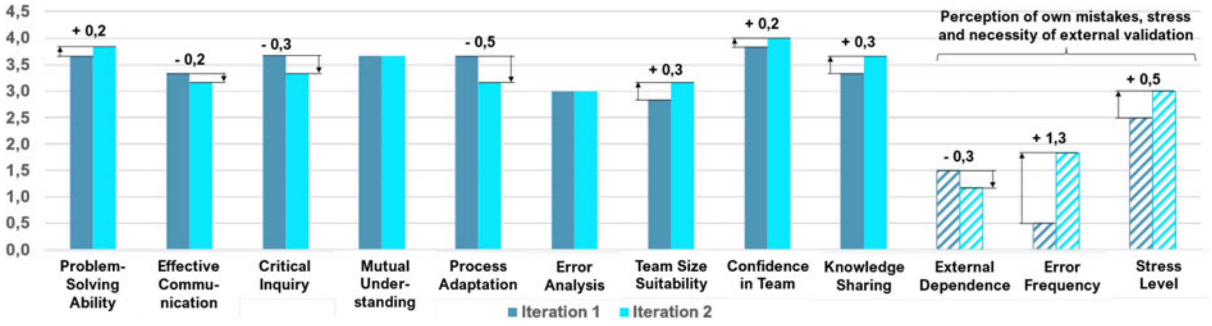


Figure 5. Average responses from the technology group

In the control group, performance improves with practice (mean tower score rises from 25 to 37), while average resilience remains near net zero change. Figure 6 shows a steady profile consistent with stabilization rather than manipulation-driven shifts; stress rises slightly (+0.2), likely reflecting end-of-task pressure in some runs rather than systematic environmental strain. As a baseline, the control trajectory helps isolate the specific effects observed in the manipulated groups and underscores the influence of practice and familiarization across iterations.

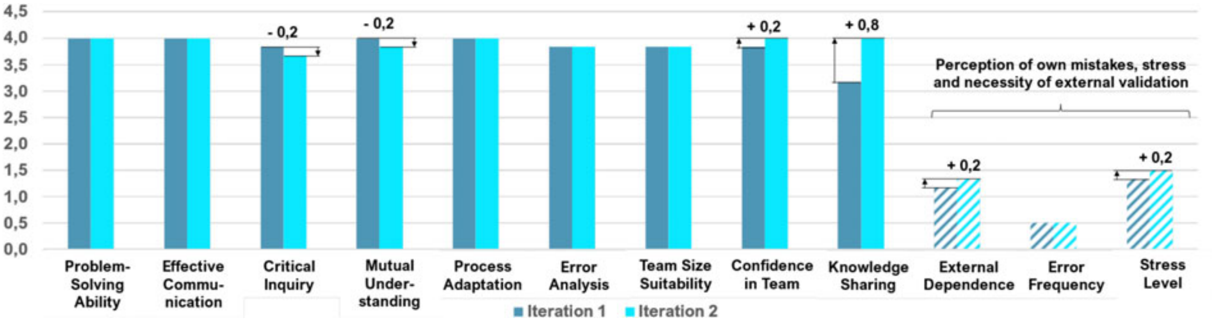


Figure 6. Average responses from the control group

7. Discussion

The results provide empirical support for the proposed mechanism environment → team resilience → teamflow. Across all conditions, teams demonstrated that resilience acts as a stabilising capacity enabling them to maintain collective performance under perturbation. However, the way in which resilience emerged differed across the manipulated environment factors, highlighting that distinct design dimensions of the engineering environment shape adaptive behaviour in specific ways. In the organisational condition, externally imposed cadence facilitated rapid recovery from coordination inefficiencies, suggesting that temporal structure can stabilise team processes when time pressure is high. In the people condition, anticipated separation triggered proactive handovers and explicit communication, indicating that transparency and redundancy in roles strengthen collective robustness. In contrast, the technology condition revealed that changes in tool context can impair adaptation when teams misjudge rebuild time or strategy fit. Together, these findings show that environment design across people, organisation, and technology dimensions directly shapes a team's ability to anticipate, absorb, and adapt—core components of resilience and prerequisites for teamflow. This pattern aligns with flow theory, which frames optimal experience as a balance between challenge and capability (Csikszentmihalyi, 1990), and with socio-technical perspectives that view well-designed environments as enablers of resilient team dynamics rather than fixed procedures. The link between resilience and collective performance indicates that teamflow emerges as a dynamic outcome of resilient interaction patterns, strengthening the theoretical bridge between engineering environment design, team resilience, and collective performance states. The data further show that unsuccessful attempts (37.5 % overall) were associated with higher stress levels (mean 2.4 vs. 1.6 in successful rounds), reinforcing the connection between environment, stress regulation, and performance. Managing cognitive load and psychological safety therefore appears central to maintaining the conditions under which teamflow can arise. From a practical perspective, even small, designable aspects of the engineering environment - such as cadence control, role continuity, and tool stability - can substantially influence a team's capacity to adapt and sustain collective focus. While the study is limited by a small sample and team size and outlier sensitivity, and by using resilience with initial teamflow indicators rather than a full teamflow construct, it provides first empirical evidence for the proposed mechanism.

8. Conclusion and outlook

This study examined how engineering environments, conceptualised as a socio-technical system across people, organisation, and technology (P–O–T), influence team resilience and the emergence of teamflow in product development teams. The results provide empirical support for the proposed mechanism environment → team resilience → teamflow, showing that resilience functions as a measurable, proximal condition through which environment factors affect collective performance states. The study contributes (i) an operationalisation of the engineering environment via a compact P–O–T questionnaire, (ii) a controlled laboratory design to test the proposed mechanism using three exemplar factors, and (iii) evidence-based guidance for designing environments that foster resilient team dynamics and create the preconditions for teamflow. Building on these results, future research will focus on advancing the measurement and active facilitation of teamflow in engineering contexts. First, a data-driven instrument will be developed to capture teamflow indicators in real time, supported by AI-based analytics to identify patterns of collective performance. Second, an intelligent assistance system will be designed to observe teamflow states and proactively provide relevant information, enabling teams to make better-informed decisions during development. Third, a Teamflow-Navigator will be created to offer methods and design principles that help practitioners actively shape their environments to increase the likelihood of achieving teamflow. Together, these developments aim to transform the understanding of teamflow from a theoretical construct into an operational capability for resilient, high-performing product development teams.

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