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Towards Advanced Collaboration Systems for Design Reviews in Product and Production Development

Francisco García Rivera*[1], Puranjay Mugur[2], Dan Li[2], Henrik Söderlund[3]

[1]University of Skövde, Skövde, Sweden
[2]Volvo Car Corporation, Gothenburg, Sweden
[3]Chalmers University of Technology, Gothenburg, Sweden

*E-mail: francisco.garcia.rivera@his.se

Abstract. Design reviews are essential checkpoints in product and production development, yet their current implementation often leads to coordination difficulties and weak traceability. This paper defines what qualifies as an advanced collaboration tool for design reviews and identifies the core capabilities that distinguish such systems from conventional setups. The study builds on workshops with two industrial partners in the automotive sector, where participants reflected on the capabilities needed for more effective collaboration. Transcribed discussions were coded into capability clusters and grouped into three categories: interaction-related, process management-related, and domain-specific. The analysis identifies three core affordances that enable more effective design reviews: shared spatial presence, in-scene deictic indication, and independent navigation with presenter follow. Supportive capabilities such as anchored documentation, lightweight roles, and integration with managed records further improve participation and traceability. The proposed definition shifts attention from specific technologies to observable affordances that enable teams to jointly reason about complex geometry. It provides a practical foundation for evaluating and implementing collaboration systems that make design reviews more participatory, accountable, and efficient.

1. Introduction

Design reviews (DRs) are formal checkpoints in the product development process where cross-functional stakeholders evaluate a design proposal against requirements and risks, determine whether work should advance or be redirected, and record accountable decisions with clear ownership and follow-up. [1], [2], [3]. DRs are structured evaluations that integrate multiple perspectives and connect technical evidence to progression criteria, ensuring decisions remain traceable over time. [4], [5].

In current practice, most DRs are run as scheduled meetings centered on a shared representation of the product, where a designated person drives the meeting, controls the view, and other participants request views, ask questions, and contribute domain-specific assessments. Co-located teams usually conduct DRs in a room with a large display and a video conference with screen-sharing CAD for hybrid or remote teams. This setup centralizes control in the hands of one operator, forcing others to communicate verbally, such as “rotate here” or “zoom on that flange.”

Empirical studies show that this driver-centric structure affects turn-taking, participation, and knowledge capture, with CAD remaining the primary visualization tool and meeting minutes serving as the main official record [3], [6], [7], [8].

DRs face recurring process management and interaction problems. On the process side, decisions, rationale, and actions are often poorly captured, scattered across tools, and sometimes disconnected from the product baseline, leading to knowledge loss and weak traceability [2], [9], [10], [11]. On the interaction side, participants struggle to share viewpoints and maintain coordinated attention, leading to friction, unstable turn-taking, and increased cognitive load, especially in remote or driver-controlled sessions where directing the shared view to the exact geometry requires repeated verbal requests. Deictic reference is often verbal rather than visual, so indications like “look at this pin” or “rotate a bit more” lead to ambiguity about the target element and its state. This problem intensifies with dense assemblies. [8], [12], [13]. Together, these findings point to a gap between the coordination needs of multi-stakeholder DRs and the affordances of conventional videoconferencing and screen-shared CAD workflows.

Research on collaboration technologies for DRs shows clear interaction benefits in immersive, multi-user environments, including improved spatial understanding, richer deictic reference, and higher engagement. [14], [15], [16]. However, much of this work remains tool-centric and stops short of specifying how these capabilities integrate into repeatable workflows with traceable outputs. Studies demonstrate that immersive technologies or multi-user viewers can help participants point, align viewpoints, and perceive scale. Yet they often evaluate these capabilities in isolation, provide limited guidance on roles and procedures, and underreport how session artifacts support downstream decisions.

Industry demand mirrors these findings. In partner workshops and case work, teams consistently described the need for multi-party presence across devices, in scene deictic communication such as point and highlight, shared manipulation with clear presenter control, and session capture that links to authoritative records like PLM. Similar needs appear in the academic literature, where surveys and case studies emphasize multi-user access to the model, integrated logging, and CAD integration as prerequisites for effective DRs [6], [17].

Here, we use the term advanced collaboration tools to denote a modality-agnostic set of capabilities that enable multi-stakeholder DRs to function as repeatable procedures. The emphasis is on what the system enables reviewers to do.

This paper addresses the lack of process-oriented guidance connecting these capabilities to actual DRs conducted and traceable outcomes. It contributes by defining the affordances that characterize advanced collaboration tools for DRs and consolidating a problem space from empirical and literature findings, emphasizing attention management, deictic clarity, and traceable capture as consistent needs across settings.

2. Method

The work reported here focuses on two companies, referred to as Company 1 and Company 2 for confidentiality. The workshops with these companies were built on an earlier joint workshop in which both industrial partners allocated a set of tokens to the capabilities they considered most important for effective collaboration during DRs.

The purpose of these follow-up workshops was to gain a deeper understanding of what industrial stakeholders value when using advanced collaboration tools in real DR situations. Both companies were invited to reflect on their current practices, experiment with new tools, and discuss what capabilities they believed would make their DRs more efficient and better supported. This step connected the broader functional priorities defined at the consortium level with the concrete needs expressed by practitioners directly involved in product and production development.

2.1 Procedure

The study combined an initial joint workshop with various companies with two follow-up workshops conducted separately at Company 1 and Company 2. The first workshop brought together representatives from several industrial partners in a research project to identify which capabilities they considered most valuable in industrial collaboration tools. Each participant listed the capabilities they considered important and allocated a limited number of tokens to indicate their priority. This exercise resulted in a ranked list of desired capabilities that reflected the companies' shared view of what an advanced collaboration system should support.

Building on these results, two refinement workshops were conducted with two manufacturing departments from different automotive companies. Company 1 included six participants (two managers and four engineers), while Company 2 included four participants (one manager and three engineers). All participants had prior experience conducting or participating in design reviews. Each session lasted about ninety minutes and was held on-site at each company's facilities. At the beginning of each session, participants were introduced to a set of representative collaboration tools, including Arkio (Reykjavík, Iceland), Gravity Sketch (Gravity Sketch London, UK), Campfire (California, USA), IPS IMMA (Gothenburg, Sweden), and Onshape (Massachusetts, USA). Six participants in Company 1 and four participants in Company 2 used these tools on 2 VR-ready laptops and two standalone headsets in a round-table, turn-taking setup. These tools were selected because they represent different approaches to collaborative 3D work. Arkio, originally targeted toward architectural collaboration, emphasizes rapid spatial layout, co-located scene composition, and device parity across VR and desktop. Campfire is a CAD visualizer and review platform that includes annotation capabilities, deictic reference, and an action-tracking system. Gravity Sketch enables multi-user 3D sketching and annotation in immersive space, supporting early ideation and in-scene communication. IPS IMMA is a simulation tool with a collaborative version that incorporates several domain-specific capabilities (including ergonomics analyses and path planning), cross-platform collaboration, and co-presence in the same virtual environment. Onshape, in contrast, provides a cloud-based CAD environment with version control, comments, and integrated task management. Together, they span exploratory ideation and spatial reasoning to structured engineering workflows, allowing participants to reflect on different aspects of collaboration relevant to their DR practices. The demonstrations were tailored to each company's typical DR workflow so participants could evaluate the relevance of each tool in context. The researcher acted as a facilitator, guiding the conversation through each of the capability clusters developed during the initial activity.

Following the demonstrations, participants discussed which of the previously identified capabilities they considered essential for their own DRs, how these compared with their current practices, and which capabilities they considered most relevant for future DR platforms. The discussion focused on clarifying what users actually meant when referring to particular capabilities, since terms like "XR" or "virtual meeting" were often used to describe broader needs such as independent viewpoint control, multi-user presence, or anchored comments. This process is illustrated in Figure 1.

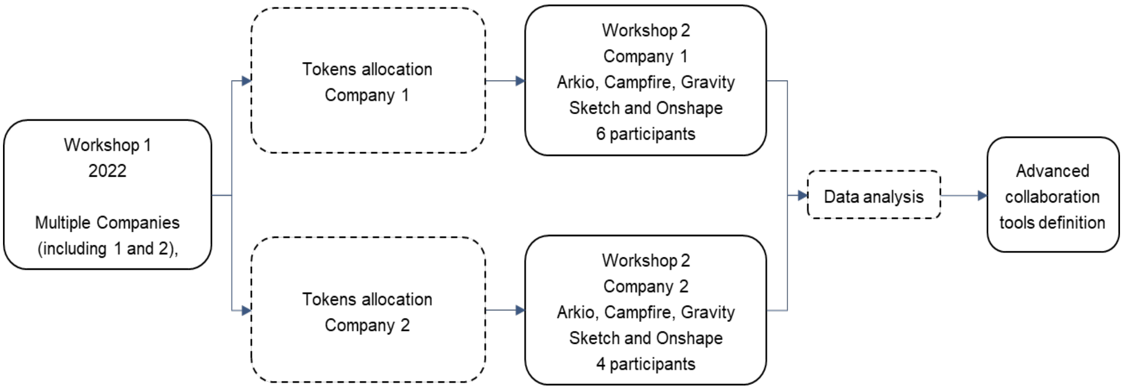

Figure 1. Study procedure

2.2 Data collection

The data for this study were collected in two main stages. The first stage consisted of the consortium workshop, where representatives from several industrial partners in a research project identified and prioritized the capabilities they considered most important for DRs. All participants from the companies had a focus on manufacturing. Each participant wrote down the capabilities they considered relevant, and each organization allocated a limited number of tokens to indicate their relative importance. The outcome of this activity was a ranked list of desired capabilities that served as a reference for the company workshops.

The second stage involved two company-specific workshops, one with Company 1 and one with Company 2. The participants worked at the manufacturing department of these companies, so their perspectives reflected that context. Both sessions were held on-site and audio recorded in full, with the consent of all participants. The audio recordings were transcribed verbatim to capture how participants described their current practices, discussed the tools demonstrated, and reflected on the capabilities identified in the consortium session. The audio files were kept in an offline folder only accessible to the research team.

After the workshops, an internal presentation prepared independently by Company 1 was shared with the research team. Although not part of the study's primary data, this document provided a useful point of comparison to verify that the interpretation of the workshop discussion was consistent with the company's internal assessment of functional requirements.

All transcripts, notes, and supporting materials were coded according to the capabilities discussed and the type of affordances they represented, including multi-user presence, viewpoint control, annotation, shared manipulation, ergonomic evaluation, and reporting. This process enabled the analysis to determine which capabilities were considered most critical for effective DRs and to ensure the interpretation aligned with industrial perspectives.

2.3 Data analysis

The analysis moved from detailed capabilities to collaboration affordances through an intermediate layer of collaboration capability clusters.

Step 1. Collaboration capability clusters from the initial activity.

The forty-seven capabilities identified within the research project consortium were used as first-cycle descriptive codes. These capabilities represented discrete technical capabilities (for example, pointing, navigation, or recording). To make the dataset analytically manageable, related or overlapping items were merged into collaboration capability clusters that capture which groups of capabilities they enable. These clusters served as a bridge between low-level software capabilities and higher-level collaboration affordances, allowing subsequent interpretation of what these technical capabilities make possible in DR practice. Each cluster was classified as either interaction-related, process management-related, or domain-specific-related, as summarized in Table 1.

After assigning the forty-seven capabilities as first-cycle descriptive codes, the first author reviewed all transcripts in multiple passes to ensure that segments were coded consistently and according to the evolving definitions of each cluster. When questions arose about whether a segment belonged to one cluster or another (for example, whether a remark reflected shared navigation or cross platform collaboration), decision rules were refined, and the earlier transcripts were re-checked to maintain consistency. This iterative refinement produced a stable set of capability clusters that then served as the basis for the second-cycle pattern coding, in which recurring intentions behind these clusters were abstracted into the collaboration affordances presented in the Results. The purpose of this step was not to increase the number of codes but to ensure a traceable and systematic transition from capabilities to clusters and to affordances.

Table 1. Consortium capabilities into collaboration categories

Example consortium capabilities	Collaboration capability categories	Classification
F14 pointing, highlighting, marking specific parts	In-scene communication	Interaction
F9, F10 role hierarchy, write-read rights, automatic leader assignment	Role and access control	Process management
F15–F17 navigation, rescaling, re-orientation capabilities	Spatial navigation and re-orientation	Interaction
F18–F21 real-time modifications, precision editing, physics simulation	Shared manipulation and testing	Interaction
F26–F28 recording, whiteboards, shared documents	Documentation and collaboration utilities	Process management
F30–F32 ergonomic assessment, posture simulation, RAMP, or EAWS analysis	Ergonomic evaluation	Domain specific
F33–F35 reporting, polling, decision capture	Traceability and decision support	Process management
F25, F42–F45 cross-platform operation, AR and VR integration	Cross-platform collaboration	Interaction

Step 2. Affordances from the workshop discussion

Verbatim workshop transcripts were reviewed line by line. Episodes that referenced or implied any collaboration capability cluster were coded accordingly, with new codes added when needs fell outside the original list, for example, PLM integration or meeting preparation routines. A second-cycle pattern analysis then grouped codes into collaboration affordances that describe the sought interaction capability rather than the discrete feature. This is exemplified in Table 2.

Table 2. Examples of workshop evidence mapped to collaboration affordances

Workshop evidence examples	Collaboration affordance	Classification
follow but step out to prepare my side; limit concurrent pointers	Attention management and viewpoint control	Interaction
everything in one place, no files on disks	Integration and workflow continuity	Process management
export action items or link to SharePoint	Documentation and traceability	Process management
one click from PLM to ensure latest model	Confidence in the data version and handoff	Process management
voting helps to close decisions	Decision support mechanisms	Process management
avatars versus webcams, need to know who speaks	Communication presence and role clarity	Interaction

An internal document from one participating partner was consulted as a verification step to check that interpretations aligned with documented priorities and was not included in the primary analysis.

The relationship between the two tables can be understood as a movement from what tools can do to what people need to do together. Table 1 captures the technical side: the discrete capabilities identified across the consortium's tools and grouped into capability clusters, such as in-scene communication or documentation utilities. Table 2 shows how these same mechanisms appeared in the workshops, where participants described what they were trying to achieve, for example, keeping everyone focused on the same area or maintaining all remarks in one shared space. The clusters, therefore, acted as a bridge between technical capabilities and observed collaboration behavior.

The transition from Table 2 to the results section follows the same logic but in reverse. The affordances identified in the workshops, such as attention management or workflow continuity, were translated back into the specific capabilities that realize them in practice. In other words, the workshop data explained what people needed to accomplish, and the final results specify which capabilities make those affordances possible. This connection ensured that the definition and minimum feature set proposed in the following section remain grounded in both the technical evidence from the consortium and the experiential evidence from the workshops.

3. Results

Building on the collaboration affordances identified in the workshops, the following section specifies the minimum system capabilities that realize these affordances in practice. The results consolidate insights from the consortium's capabilities, workshop discussions, and field observations into a coherent capability set that defines what qualifies as an advanced collaboration tool for DRs.

Definition

An advanced collaboration tool for DRs is any digital environment that enables multi-party joint inspection of geometry with shared and independent navigation, in-scene deictic indication, and ideally, supports a meeting record that persists decisions and references so they can be carried into managed product data. The definition is modality-agnostic and focuses on what collaborators can do together and the artifacts they leave behind.

Core capabilities set

Three capabilities are required for a platform to qualify under this definition. First, a shared spatial environment where multiple users are present at the same time, with optional visibility into each other's focus and actions. Second, in-scene deictic references, such as point, highlight, sketch, or anchored annotation, are linked to model geometry. Third, independent inspection controls, together with an optional presenter-follow mode, so reviewers can explore details and then collapse back to a common view for decisions. These capabilities support joint attention, grounding, and workspace awareness during inspection and were repeatedly requested and exercised in our sessions. Capture of decisions and references was also highly valued across discussions, though participants generally treated it as a supportive feature rather than part of the qualifying core. Across two ninety-minute refinement workshops using each team's own case, participants endorsed device parity for pointing and following, asked for visible indication rather than voice-only cues, and emphasized the need for identifiers to carry over so that snapshots and decisions map to managed objects.

Earlier field observations documented recurrent problems in everyday remote DRs [18], particularly when core capabilities were absent. Teams without shared presence, in-scene indication, or independent navigation often struggled to align on the same geometry, relied on verbal descriptions that led to ambiguity, and produced fragmented records detached from the model state. In the follow-up workshops, participants recognized these difficulties and agreed that they reflected the lack of the capabilities defined as essential in this study.

The value of specific affordances was articulated through the participants' reflections on the limitations of their current tools compared to the capabilities of the collaborative environment. For instance, discussions highlighted that Independent Navigation is critical for enabling parallel cognitive work. Participants noted that in conventional 'single-driver' reviews, verifying a specific concern requires interrupting the presenter with ambiguous verbal instructions, such as asking them to "please go to that [area], not that one". In contrast, they argued that the ability to "step out of the following mode" would allow them to inspect off-screen areas autonomously and "prepare [their] side of the story" without disrupting the main discussion flow. Furthermore, participants identified In-scene Deictic Referencing as a necessary solution to the "messy" nature of referring to complex geometry without shared pointers. These reflections confirm that the identified affordances are not merely novel features but functional requirements that address specific coordination bottlenecks in engineering communication

Several capabilities were consistently valued yet treated as complementary rather than necessary to qualify as an advanced collaboration tool. Review safe manipulation, such as reveal, hide, sectioning, and slicing, helped with inspection without altering product data. Roles and permissions supported orderly turn-taking. Simple integration and handoff capabilities, such as export packs and action items, kept decisions within the product baseline, and some domain-specific capabilities, including ergonomic analyses, collision avoidance, and path planning. However, they are often the capabilities that differentiate one platform from another and define the specific market or user group each tool targets.

Boundary cases

Immersive devices can greatly strengthen spatial perception, yet immersion alone does not satisfy the definition. A videoconference with someone screen-sharing an immersive view, but without in-scene indication or independent navigation, fails the boundary criteria, even if high-quality CAD is visible. Conversely, a desktop viewer that provides presence, deictic indication, and shared and independent navigation meets the definition. This boundary keeps the construct tied to observable affordances rather than to modality labels.

Summary
The definition and minimum feature set are grounded in workshop dialogue, field observations of routine DRs, and verified capability demonstrations on partners' own models. Together, they specify a small, modality-agnostic core: shared presence with legible focus and actions, in-scene deictic indication bound to geometry, and shared and independent navigation with presenter follow. Platforms that provide this core enable joint inspection and leave a record that can persist into managed product data. Table 3 summarizes the derived capability tiers.

Table 3. Description of advanced collaboration tools.

Tier	Capability	Inclusion rule	What it looks like in session	Evidence in our data
Core (required)	Shared presence with legible focus and actions.	Mandatory for qualification. Multiple participants co-present in the same scene with visibility of where others are looking or acting.	Names/avatars visible, live cursors or focus indicators, quick "bring everyone" recenter.	Capability checklist confirmed presence and focus cues across sessions; "bring everyone" was used to stop drift.
Core (required)	Independent navigation plus presenter follow.	Mandatory for qualification. Reviewers can explore locally and rejoin a shared view instantly when needed.	Participant inspects a detail, then follows the presenter through a countdown switch.	Operational codes for navigate/follow, start-in-follow, and recenter moves were endorsed in both workshops.
Core (required)	In-scene deictic indication bound to geometry.	Mandatory for qualification. Pointing, highlighting, or anchored marks are visible to all and tied to model elements.	Highlight the target part, verbal acknowledgment, and fewer "rotate a bit" requests.	Codes for point/highlight and anchor; participants asked to cap simultaneous pointers.
Supportive (recommended)	Anchored capture of decisions and rationale.	Recommended for traceability but not required for qualification.	Scribe creates an anchored snapshot per topic, reads back the decision, and exports the pack.	Documentation and traceability prescriptions; export steps and field mapping.
Supportive (recommended)	Lightweight roles and permissions.	Recommended for orderly turn-taking; strengthens flow control.	Single presenter at a time, explicit handoff, reviewer indicates via shared highlight.	Attention management card shows presenter handoff and highlight protocol.
Supportive (recommended)	Linkage to managed records.	Recommended for data continuity; enables persistence into PLM.	One-click launch from the system of record; decisions become tickets with snapshot links.	Workshop notes emphasize the latest-model trust and ID carry-over; integration steps and KPIs.
Complementary (optional)	Review safe inspection tools.	Optional; improves inspection without altering product data.	Sectioning, slicing, revealing/hiding during discussion.	Treated as add-ons in feature lists and workshop edits.
Domain-specific (context-dependent)	Ergonomic analyses, collision avoidance, etc.	Relevant only in specific application domains; extend the tool's scope beyond general collaboration.	Simulating posture, checking reachability, and validating assembly sequences.	Reported by participants working with ergonomics and manufacturing use cases

4. Discussion

This study provides a baseline definition for what qualifies as an advanced collaboration tool in the context of DRs. The proposed definition centers on what the system allows participants to do together: inspect geometry collaboratively, communicate in the scene through anchored or highlighted references, and generate outputs that persist as structured records. These capabilities complement established presenter-led workflows and, when appropriate, help sessions shift toward more shared inspection and mutual understanding.

What makes these findings relevant is that they consolidate the necessary capabilities into a small, evaluable set grounded in observed practice. The data show that shared spatial presence, deictic clarity, and independent navigation were seen as a solution to reduce the ambiguity and coordination overhead common in hybrid or remote DRs. These elements align with principles from distributed cognition and media richness theory, which emphasize the importance of shared attention and communication bandwidth in complex, multi-stakeholder tasks. [19], [20], [21], [22]. In this sense, a collaboration platform becomes “advanced” not by virtue of immersion or visual fidelity, but by how well it enables interaction patterns that support joint reasoning over complex geometry.

The analysis also distinguishes between interaction, process management, and domain-specific capabilities. Interaction capabilities refer to the immediate exchange of information and spatial understanding during the session, how participants navigate, point, follow, or annotate to maintain a shared focus on the model. Process management capabilities are related to how the meeting is organized and sustained: who initiates and leads, how participants take turns, how viewpoints are prepared, how information is captured, and how outcomes connect to managed data. Domain-specific capabilities refer to those that support specialized evaluations, such as ergonomics or manufacturability, beyond general communication and coordination. This distinction is a helpful way of thinking about what DRs need and can help practitioners identify where their DRs are falling short.

A fast-moving set of platforms is emerging in this space, including Arkio (Reykjavik, Iceland), Campfire (California, USA), CoLab (Newfoundland, Canada), Gravity Sketch (London, UK), Onshape (Massachusetts, USA), ShapesXR (California, USA), IPS IMMA (Gothenburg, Sweden), and Autodesk VRED (California, USA). Although they share a family resemblance, they differ in how strongly they emphasize interaction or process management and in the extent to which they incorporate domain-specific capabilities, which often reflect the industries they target and shape how collaboration, visualization, and workflow integration are implemented. Although not all of them were used in this study, ShapesXR is designed for early-stage concept work, enabling teams to co-create and review spatial layouts and prototypes. VRED concentrates on high-fidelity product visualization and real-time collaboration to validate visual and material details. Campfire focuses on cross-device 3D DRs with shared presence and in-scene communication across desktop and XR, with a focus on sharing, annotating, and reviewing models. Onshape combines cloud-native CAD with built-in product data management and release management to support version control, branching, approvals, and enterprise workflow integration. IPS IMMA targets assembly and ergonomics by simulating human motion, reachability, posture load, and collision-free paths to assess feasibility and support workplace design. The affordance-based definition developed in this paper offers a neutral way to describe what these tools actually enable, to compare them across emphases, and to align selections with local needs without relying on modality labels or vendor positioning.

Still, the scope of this study is intentionally narrow. It draws on two focused workshops in the Swedish automotive sector, involving teams from the manufacturing departments of two companies. Company 1 included six participants (two managers and four engineers), while Company 2 included four participants (one manager and three engineers). The findings, therefore, reflect the conditions, tools, and terminology of that specific industrial context. While the patterns identified here align with broader literature and prior field observations, further replication across other industries, design stages, and team configurations is needed to assess generalizability. Even so, the proposed definition provides a practical starting point for organizations aiming to evaluate or implement collaboration systems with clearer expectations and more deliberate design choices.

Looking ahead, there is room for both technical and empirical extensions. Future studies could connect collaboration capabilities to measurable outcomes such as decision quality, cycle time, or spatial comprehension. Social dynamics also require deeper attention, including how presence indicators, control handoff, and deictic cues affect role clarity and participation equity in multi-user environments.

Our aim is not to offer a definitive answer, but to propose a clearer way of thinking about what advanced collaboration should enable in practice. By grounding the discussion in observable affordances rather than interface types or branding, the work invites a shift in how we define, select, and improve the systems that shape collaborative design.

5. Conclusion

This paper proposes an affordance-based definition of what qualifies as an advanced collaboration tool for DRs and specifies the minimum capabilities required to realize those affordances in practice. The core is small and generalizable: shared presence with legible focus and actions, in-scene deictic indication bound to geometry, and independent navigation with presenter follow. These capabilities directly address the recurring problems observed in routine DRs when such capabilities are absent, including misaligned views, ambiguous verbal reference, and fragmented records detached from the model state.

Supportive capabilities such as anchored capture of decisions, lightweight roles and permissions, and linkage to managed records strengthen traceability and flow. Domain-specific capabilities, including ergonomic evaluation, collision avoidance, and path planning, do not define whether a system qualifies as advanced, yet they are often what differentiate platforms and anchor them to particular industries. The boundary criteria, therefore, remain tied to observable collaboration affordances rather than modality labels, while still acknowledging that domain capabilities shape how interaction and process management are implemented.

For practice, the definition offers clear purchase criteria and implementation guidance. Teams can evaluate candidate platforms by asking whether joint inspection, shared attention, and swift convergence on a common view are reliably enabled and whether session artifacts persist into managed data. For research, the work provides a basis to connect capabilities with outcomes such as decision quality, cycle time, and participation equity, and invites studies that compare alternative implementations of the same affordance across devices and contexts.

The study is grounded in two focused workshops and prior field observations in the Swedish automotive sector and reflects that context. Broader validation across domains, stages of the product development process, and team configurations is a next step. Even within this scope, the results show that centering evaluation on collaboration affordances clarifies what matters in DRs and helps organizations select and configure tools that make reviews more participatory, accountable, and efficient.

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