
EMBODIED INTELLIGENCE AND WORLD MODELS: A SURVEY OF PROGRESS FROM 2024 TO EARLY 2026

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ABSTRACT

Embodied intelligence requires agents to perceive, reason, and act under real-world physical constraints while adapting online to new tasks and environments. Over the last year, the field has rapidly shifted from modular pipelines toward large-scale vision-language-action (VLA) policies and world-model-based control stacks, with increasing emphasis on long-horizon robustness, data efficiency, and cross-embodiment transfer [Liang et al., 2025a, Liu et al., 2025a, Li et al., 2025a, Fung et al., 2025]. This survey reviews research from January 2024 to February 2026 and organizes the literature with a coupled framework: an embodied-agent pipeline view (perception, planning, control, adaptation) and a world-model design view (functionality, temporal modeling, and spatial representation). We synthesize representative advances in foundation VLAs, embodied world models, policy refinement, and benchmark design [Kim et al., 2024, Intelligence et al., 2025a, Black et al., 2026, Team et al., 2025a, Chen et al., 2026a, Upadhyay et al., 2026]. We further formalize the common learning objective that links latent dynamics modeling with decision optimization, clarifying where current systems gain performance and where they fail under distribution shift, partial observability, and closed-loop compounding errors [Gupta et al., 2024, Wan et al., 2025, Team et al., 2025b]. Finally, we provide an auditable citation-coverage appendix generated from 318 collected papers, plus explicit exclusion rules for non-embodied or out-of-window works, to support transparent and reproducible survey writing.

Keywords: embodied AI, world models, vision-language-action models, robotic foundation models, long-horizon planning

1 Introduction

Embodied AI studies agents that close the full interaction loop with the physical world: sensing, state estimation, decision making, and low-level action execution under uncertainty and resource constraints. Classical task settings such as rearrangement and instruction-conditioned navigation established this closed-loop perspective early, and also highlighted the gap between benchmark success and robust real-world deployment [Batra et al., 2020, Duan et al., 2022]. Recent progress in large multimodal models, robot foundation policies, and scalable data pipelines has substantially accelerated the field [Brohan et al., 2023, Bousmalis et al., 2023, Driess et al., 2023, Kim et al., 2024, Black et al., 2026].

In parallel, world models have re-emerged as a central abstraction for embodied decision making. Instead of treating policy learning as a purely reactive mapping from observations to actions, world-model methods explicitly or implicitly learn transition structure and use it for imagination, evaluation, and planning [Gupta et al., 2024, Ding et al., 2025a,

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Li et al., 2025a]. This trend is visible across robot manipulation, autonomous driving, and general multimodal control stacks, where latent rollouts, video-conditioned prediction, or hybrid generative dynamics are increasingly used to improve sample efficiency and long-horizon consistency [Fung et al., 2025, Wan et al., 2025, Team et al., 2025b, Chen et al., 2026a].

1.1 Scope and Inclusion Criteria

This survey covers work from **January 1, 2024 to February 27, 2026**. We adopt a strict embodied criterion: a paper is in scope when its method or benchmark directly supports closed-loop physical interaction, robot control, embodied decision making, or embodied world-modeling. Purely generic sequence modeling or non-embodied world simulation is excluded from the core set and recorded in an auditable exclusion appendix.

We use two synchronized views:

- **Embodied pipeline view:** perception, planning/reasoning, control, and adaptation.
- **World-model view:** functionality (decision-coupled vs. general-purpose), temporal modeling (stepwise vs. global), and spatial representation (compact latent, tokenized, geometric, or hybrid).

This dual view is motivated by the observation that modern VLA systems blur traditional module boundaries. Many recent methods couple high-level language reasoning with low-level visuomotor control while integrating learned predictive priors to stabilize long-horizon behavior [Intelligence et al., 2025a,b, Zheng et al., 2025a, Li et al., 2025b, Cen et al., 2025a].

1.2 Why a New Survey Is Needed

Multiple surveys now cover embodied AI, world models, or VLA development from different angles [Liu et al., 2025a, Liang et al., 2025a, Lu and Tang, 2025, Shao et al., 2025, Zhang et al., 2025a, Fan et al., 2026, Yu et al., 2026a]. However, three gaps remain.

First, many reviews are either broad but shallow on algorithmic coupling, or deep on world models but not tightly connected to embodied control decisions. Second, year-scale progress in 2025–2026 has changed the practical frontier quickly, including open-world VLA generalization, reinforcement-style post-training for robots, and embodied world-model benchmarks [Intelligence et al., 2025a,b, Upadhyay et al., 2026, Wu et al., 2026a]. Third, reproducibility in survey writing is often limited by unclear inclusion rules and incomplete citation traceability.

1.3 Contributions

This survey makes four concrete contributions:

- We provide a **decision-oriented synthesis** of embodied intelligence and world models under a single coupled taxonomy.
- We formalize a **shared learning objective** that links latent dynamics learning and downstream control optimization.
- We summarize **recent advances (2024–2026)** across VLA architectures, embodied world-modeling, data/benchmark design, and policy refinement [Kim et al., 2024, NVIDIA et al., 2025a,b, Black et al., 2026, Mei et al., 2026].
- We release an **auditable citation coverage workflow** from 318 collected references, including in-scope grouping and explicit exclusion reasons.

1.4 Paper Organization

Section 2 introduces formal foundations and a unified notation for embodied interaction and world-model training. Section 3 presents the coupled taxonomy and representative methods. Section 4 summarizes data resources and evaluation protocols. Section 5 discusses cross-family comparisons and tradeoffs. Section 6 distills open challenges and forward-looking directions. Section 7 concludes.

2 Background and Mathematical Formulation

2.1 Embodied Interaction as a Partially Observable Control Process

We model embodied interaction as a partially observable Markov decision process (POMDP):

$$\mathcal{M} = (\mathcal{S}, \mathcal{A}, \mathcal{O}, p, \Omega, r, \gamma), \quad (1)$$

where $s_t \in \mathcal{S}$ is the latent world state, $a_t \in \mathcal{A}$ is the control action, and $o_t \in \mathcal{O}$ is the observation stream (RGB, depth, force, language context, proprioception). The environment follows

$$s_{t+1} \sim p(s_{t+1} | s_t, a_t), \quad o_t \sim \Omega(o_t | s_t). \quad (2)$$

Embodied agents optimize discounted return

$$J(\pi) = \mathbb{E}_{\pi, p} \left[\sum_{t=0}^T \gamma^t r(s_t, a_t) \right]. \quad (3)$$

Compared with pure simulator RL settings, deployed embodied systems must satisfy strict constraints on reaction latency, safety, action smoothness, and distribution shift under long horizons [Intelligence et al., 2025a,b, Black et al., 2026, Wu et al., 2026b].

2.2 Latent World Models for Embodied Control

A practical world model introduces latent states z_t to capture controllable scene dynamics:

$$z_t \sim q_\phi(z_t | o_{\leq t}, a_{<t}), \quad \hat{z}_{t+1} \sim p_\theta(z_{t+1} | z_t, a_t). \quad (4)$$

The decoder or predictor head maps latent trajectories back to observation and task-relevant signals:

$$\hat{o}_{t+1} \sim p_\theta(o_{t+1} | \hat{z}_{t+1}), \quad \hat{y}_{t+1} = g_\psi(\hat{z}_{t+1}), \quad (5)$$

where \hat{y}_{t+1} may denote object states, occupancy, contact events, or value estimates, depending on the downstream stack [Li et al., 2025a, Fung et al., 2025, Team et al., 2025b, Berg et al., 2025].

Most implementations optimize a reconstruction-regularization-task objective:

$$\mathcal{L} = \underbrace{\mathcal{L}_{\text{obs}}}_{\text{prediction/reconstruction}} + \beta \underbrace{\text{KL}[q_\phi(z_t | \cdot) \| p_\theta(z_t | z_{t-1}, a_{t-1})]}_{\text{dynamics consistency}} + \lambda \underbrace{\mathcal{L}_{\text{task}}}_{\text{control/planning utility}}. \quad (6)$$

The key distinction in modern embodied literature is not whether this decomposition exists, but where decision coupling is applied: end-to-end VLA policy heads, model-predictive planning over latent rollouts, hybrid actor-model loops, or offline-to-online adaptation pipelines [Kim et al., 2024, Li et al., 2025b, Cen et al., 2025a, Wan et al., 2025, Shen et al., 2026].

2.3 Decision Optimization with Learned Dynamics

Given a learned model, open-loop planning over horizon H can be written as

$$\mathbf{a}_{t:t+H-1}^* = \arg \max_{\mathbf{a}_{t:t+H-1}} \mathbb{E}_{p_\theta} \left[\sum_{k=0}^{H-1} \gamma^k \hat{r}_{t+k} \right]. \quad (7)$$

In practice, embodied systems rarely execute Eq. 7 in pure form. They combine short-horizon replanning, policy priors, and intervention signals to control compounding errors [Intelligence et al., 2025b, Li et al., 2025c, Lu et al., 2025, Chen et al., 2025a].

2.4 Failure Modes in the 2024–2026 Regime

Recent work repeatedly identifies three bottlenecks:

- **Long-horizon drift:** rollout quality degrades over multi-stage tasks, especially when contact dynamics and object geometry shift.

- **Representation mismatch:** action-space controls and pixel-space predictors are weakly aligned without embodiment-aware conditioning [Chen et al., 2026a, Guo et al., 2026].
- **Evaluation gaps:** pixel fidelity and short-horizon success can hide causal or physically inconsistent behavior; benchmark design is now moving toward embodied stress tests [Upadhyay et al., 2026, Wu et al., 2026a, Valle et al., 2025].

These failure modes motivate the coupled taxonomy in the next section.

3 Coupled Taxonomy of Embodied Intelligence and World Models

We organize recent methods along two synchronized dimensions: (i) the embodied decision stack and (ii) world-model design choices. This decomposition keeps algorithmic comparisons explicit while preserving system-level relevance.

3.1 Taxonomy Construction and Coverage

Our audit marks 279 papers as in-scope (2024–2026), with a strong 2025 concentration (216 papers), followed by 2026 early-stage growth (37 papers) and a smaller 2024 transition set (26 papers). The distribution is highly skewed toward system-oriented embodied implementations: 147 papers are grouped under data/benchmark/evaluation-oriented systems, 38 under agent architecture, and 36 under planning/reasoning. In contrast, explicitly labeled world-model-core papers remain a smaller but technically influential set (16 papers), often driving ideas reused by larger VLA stacks.

This distribution motivates a coupled taxonomy rather than a single-axis classification. A purely architecture-centric taxonomy hides deployment-critical differences in data flow and optimization regime; a purely task-centric taxonomy hides why similarly scoped systems diverge in stability, sample efficiency, and compute requirements.

3.2 Axis A: Functionality Coupling

Decision-coupled world models are trained and evaluated for direct control impact (policy improvement, planning reliability, intervention reduction). Representative examples include online-refined VLA pipelines and world-model-guided policy optimization [Intelligence et al., 2025b, Li et al., 2025b, Zang et al., 2025, Zhu et al., 2025a].

General-purpose world models prioritize broad predictive capability and transfer, then attach downstream controllers. This line includes large pretraining efforts and multimodal dynamics models used as reusable priors [NVIDIA et al., 2025b, Team et al., 2025b, Fan et al., 2026, Yin et al., 2026].

In practice, the key separator is *optimization target*. Decision-coupled models directly optimize task-facing losses (success, intervention, or value improvement) under closed-loop rollout constraints. General-purpose models prioritize reusable predictive competence, often scaling with heterogeneous data and delaying control coupling to post-training.

The two settings are complementary rather than contradictory: many successful systems pretrain in a general-purpose regime and then switch to decision-coupled adaptation for target deployment [Intelligence et al., 2025a,b, Black et al., 2026, Li et al., 2025c, Lu et al., 2025].

3.3 Axis B: Temporal Modeling

Sequential rollouts simulate future states step by step and align naturally with MPC-style control, but face compounding error over long horizons [Li et al., 2025a, Fung et al., 2025, Cen et al., 2025a].

Global prediction methods forecast larger trajectory segments or future differences in parallel and can improve efficiency, but require stronger structural priors to preserve causal consistency [Wan et al., 2025, Mei et al., 2026, Wang et al., 2026].

This temporal choice can be viewed as a bias-variance-compute tradeoff. Let ϵ_t denote one-step model error in latent space. In a simplified sequential regime, rollout error can scale approximately as

$$\mathcal{E}_{t+H} \propto \sum_{k=0}^{H-1} \|\epsilon_{t+k}\|, \quad (8)$$

which explains sensitivity in long-horizon manipulation and multi-agent traffic forecasting. Global predictors reduce iterative accumulation steps but can underfit local control-relevant transitions unless they include action- and embodiment-aware constraints [Chen et al., 2026a, Guo et al., 2026, Zhou et al., 2026].

Recent hybrids combine chunk-wise global prediction with local sequential correction, effectively using coarse global proposals and fine-grained control-time refinement [Team et al., 2025a, Shen et al., 2026, Wu et al., 2026c].

3.4 Axis C: Spatial Representation

Compact latent representations support real-time control and low compute budgets. **Tokenized representations** improve multimodal alignment with language-conditioned reasoning. **Geometry-aware or rendering-aware representations** better preserve view consistency and object-level structure for manipulation and driving scenarios [Chen et al., 2026a, Li et al., 2025d, Sun et al., 2025a, Zhang et al., 2025b].

From a deployment perspective:

- **Compact latent states** are favorable when control frequency and onboard compute dominate constraints.
- **Tokenized states** are favorable when semantic alignment with language and chain-of-thought style planning is critical.
- **Geometry-aware states** are favorable when camera viewpoint shift, scene rearrangement, or contact geometry consistency is central.

No single representation is dominant across all tasks. Systems that report robust real-world transfer commonly use representation mixtures (e.g., semantic tokens + geometric priors + low-level action heads) rather than a single latent form [Intelligence et al., 2025a,b, Chen et al., 2026a, Zhang et al., 2026a].

3.5 Embodied Pipeline Mapping

Across 2024–2026 papers, we observe a recurrent template:

1. foundation pretraining over heterogeneous robot or video data,
2. adaptation via task conditioning and action-space alignment,
3. post-training or online correction for deployment robustness.

This pattern appears in VLA scaling work, benchmark-driven systems, and world-model-centered planning frameworks [Kim et al., 2024, Intelligence et al., 2025a, Black et al., 2026, Upadhyay et al., 2026, Wu et al., 2026c].

To make this mapping operational, we define three interface contracts:

- **Representation contract:** what state is shared between perception, prediction, and control.
- **Temporal contract:** what horizon each module commits to and how uncertainty is propagated.
- **Feedback contract:** how online corrections (human interventions, reward feedback, safety filters) update policy/model components.

These contracts clarify why many failures are *interface failures*, not merely backbone failures. Two systems with similar backbone scale can show different field behavior because they differ in interface consistency across planning, control, and adaptation loops [Li et al., 2025b, Wang et al., 2025a, Wu et al., 2026a].

4 Data Resources and Evaluation Metrics

4.1 Data Regimes

Recent embodied research uses four complementary data regimes:

- **Simulation-first corpora** for scalable policy/world-model pretraining.
- **Interactive benchmark suites** for closed-loop reproducibility.
- **Large offline robot datasets** for foundation model initialization.
- **Real-world deployment logs** for post-training and robustness analysis.

Representative resources include OpenVLA/Open-X style pipelines, DROID-scale data, and newer embodied world-model benchmarks focused on rollout quality and control relevance [Kim et al., 2024, Collaboration et al., 2025, Khazatsky et al., 2025, Upadhyay et al., 2026, Wu et al., 2026a].

Simulation-first corpora remain the fastest path for broad pretraining and ablation-heavy development. **Interactive benchmark suites** improve comparability but can overfit to narrow task interfaces when evaluation protocols are static. **Offline robot datasets** enable large-scale behavioral priors but inherit teleoperation and sensor bias. **Real-world logs** are the only reliable source for intervention dynamics, recovery behavior, and edge-case calibration [Team et al., 2024, Fei et al., 2025, Intelligence et al., 2025b, Wu et al., 2026b].

4.2 Data Curation Dimensions

Beyond raw scale, we find four curation dimensions that strongly affect downstream behavior:

1. **Embodiment diversity** (single-arm, dual-arm, mobile manipulation, driving stacks).
2. **Task horizon composition** (short atomic skills vs. multi-stage household workflows).
3. **Interaction richness** (contact-heavy manipulation, tool use, intervention events).
4. **Annotation granularity** (language, subgoal, proprioceptive traces, safety labels).

Papers that only scale data volume without balancing these dimensions often improve headline benchmark averages but underperform in open-world deployment conditions [Intelligence et al., 2025a,b, Li et al., 2025b, Valle et al., 2025].

4.3 Metric Families

We group evaluation metrics into five families:

1. **Task success and completion quality** (success rate, throughput, long-horizon completion).
2. **Control stability and safety** (collision, intervention, recovery latency).
3. **Prediction fidelity** (perceptual quality, trajectory agreement, state consistency).
4. **Generalization** (new scene, new object, new instruction, cross-embodiment transfer).
5. **Efficiency** (token/action efficiency, runtime latency, memory/compute cost).

Several recent papers explicitly report tradeoffs between closed-loop gains and compute/latency costs, making efficiency metrics first-class rather than optional [Pertsch et al., 2025, Yang et al., 2025a, Guan et al., 2025, Shen et al., 2026].

A minimal closed-loop metric set can be formalized as:

$$\text{SR} = \frac{1}{N} \sum_{i=1}^N \mathbf{1}[\text{task } i \text{ succeeds}], \quad (9)$$

$$\text{IR} = \frac{1}{N} \sum_{i=1}^N \frac{n_i^{\text{intervention}}}{T_i}, \quad (10)$$

$$\text{RTF} = \frac{\text{inference + planning time}}{\text{control horizon time}}, \quad (11)$$

where SR measures task competence, IR captures autonomy reliability, and RTF captures real-time feasibility. This triad is often more diagnostic than isolated success-rate reporting.

4.4 Evaluation Protocol Recommendations

For reproducible and decision-relevant reporting, we recommend:

- reporting at least one metric from each family (task, safety, prediction, generalization, efficiency),
- separating in-distribution and shifted-distribution performance,
- reporting intervention-aware curves (success vs. allowed interventions),
- documenting compute budget, control frequency, and model update policy.

These elements are increasingly present in recent benchmark-oriented work and should become default for embodied world-model evaluation [Upadhyay et al., 2026, Wu et al., 2026a, Wang et al., 2025a].

Table 1: Qualitative comparison of representative embodied AI method families (2024–2026).

Family		Typical Strength	Typical Limitation	Representative Works	Deployment Fit
Foundation policies	VLA	Strong instruction following, broad skill prior	Data and compute intensive; brittle OOD recovery	[Kim et al., 2024, Intelligence et al., 2025a, Black et al., 2026]	General-purpose manipulation
World-model-guided control		Better planning signal, sample efficiency, counterfactual reasoning	Model bias and rollout drift at long horizon	[Cen et al., 2025a, Wan et al., 2025, Chen et al., 2026a]	Long-horizon decision tasks
Post-training RL/refinement for VLAs		Improves task throughput and robustness in deployment	Requires safe data collection and intervention design	[Intelligence et al., 2025b, Li et al., 2025b, Lu et al., 2025]	Continuous improvement loops
Efficiency-oriented compression/adaptation		Lower latency and memory cost; easier edge use	Potential capability drop if over-compressed	[Pertsch et al., 2025, Yang et al., 2025a, Shen et al., 2026]	Resource-constrained systems

4.5 Current Gaps

Despite progress, metric mismatch remains common: image-level prediction quality may not imply physically correct interaction outcomes, and short-horizon gains may not transfer to multi-stage tasks [Gupta et al., 2024, Valle et al., 2025, Wang et al., 2025a]. This gap motivates evaluation protocols that jointly report dynamics realism, decision quality, and deployment behavior.

5 Cross-Family Comparison and Practical Tradeoffs

Table 1 summarizes high-level differences among major method families. We intentionally avoid aggregating incompatible absolute numbers across heterogeneous tasks; instead, we compare design tendencies and deployment implications.

5.1 Comparison Protocol

To avoid misleading cross-paper claims, we compare families under a normalized decision utility view:

$$\mathcal{U} = \alpha \cdot \text{SR} - \beta \cdot \text{IR} - \gamma \cdot \text{RTF}, \quad (12)$$

where SR is task success rate, IR is intervention rate, and RTF is real-time factor (defined in Section 4). Coefficients (α, β, γ) are application-specific (e.g., higher β for safety-critical manipulation).

This formulation makes explicit that many published gains reflect different operating points, not universal dominance. For example, some models maximize SR under generous compute budgets, while others trade slight SR drops for stable real-time deployment [Pertsch et al., 2025, Yang et al., 2025a, Shen et al., 2026].

5.2 Where Each Family Wins

Foundation VLAs are strongest when broad instruction-space generalization and rapid task onboarding are primary goals. Their weakness is often intervention-heavy recovery under compounding distribution shift [Kim et al., 2024, Intelligence et al., 2025a, Black et al., 2026].

World-model-guided stacks are strongest in long-horizon reasoning and counterfactual evaluation, particularly when explicit predictive structure can guide planning. Their weakness is representation mismatch and rollout bias when embodiment-specific constraints are weakly encoded [Cen et al., 2025a, Wan et al., 2025, Chen et al., 2026a, Guo et al., 2026].

Post-training RL/refinement methods are strongest in closing deployment gaps. Notably, several reports show substantial throughput and failure-rate improvements after online or intervention-aware refinement, indicating that static imitation pretraining is no longer sufficient for robust field behavior [Intelligence et al., 2025b, Li et al., 2025b, Lu et al., 2025, Chen et al., 2025a].

Efficiency-focused methods are strongest for latency-constrained and edge scenarios, where compute-aware tokenization, pruning, and adaptation directly influence viability. Their main risk is capacity loss if compression is applied without task-specific calibration [Pertsch et al., 2025, Guan et al., 2025, Yang et al., 2025a, Shen et al., 2026].

5.3 Observed System-Level Pattern

Across recent systems, we observe a stable two-stage recipe:

1. build a large prior (foundation VLA or general world model),
2. recover reliability by decision-coupled adaptation (online RL, intervention correction, or planner-policy co-training).

This pattern appears in both robot manipulation and embodied world-model pipelines and suggests that future gains will come less from single-model scaling alone and more from adaptive closed-loop training and evaluation infrastructure [Team et al., 2025a,b, Upadhyay et al., 2026, Wu et al., 2026a].

Three practical tradeoffs dominate implementation decisions:

- **Breadth vs. controllability:** broader pretrained priors improve zero-shot behavior, but explicit dynamics constraints often improve reliability under contact-rich manipulation.
- **Long-horizon quality vs. real-time compute:** richer predictive rollouts can improve planning quality but may violate deployment latency budgets.
- **Offline scale vs. online adaptation:** larger pretraining sets improve base competence, while online refinement remains critical for domain shift.

6 Open Challenges and Outlook

6.1 Challenge 1: Long-Horizon Physical Consistency

Many systems still degrade on multi-stage tasks where small model errors accumulate into irreversible failures. Future work should prioritize physically grounded temporal constraints and intervention-aware planning objectives, not only visual realism metrics [Gupta et al., 2024, Team et al., 2025b, Wang et al., 2026].

Two technical gaps are central: (i) weak causal invariants under contact and object rearrangement, and (ii) limited uncertainty calibration in long-horizon rollouts. Without these, planners over-trust model predictions and produce brittle control sequences under distribution shift.

6.2 Challenge 2: Embodiment-Aware Representation Alignment

A recurring issue is mismatch between action-space commands and visual prediction space. Approaches that inject embodiment structure (kinematics, camera geometry, contact priors) are promising but not yet standardized [Chen et al., 2026a, Guo et al., 2026, Sun et al., 2025a].

This mismatch is no longer a niche issue; it affects generalization across robot morphologies, viewpoint changes, and tool-based manipulation. A key direction is to define representation interfaces that are simultaneously planner-friendly, control-grounded, and computationally efficient.

6.3 Challenge 3: Evaluation for Deployment, Not Only Benchmarks

Benchmark success remains an incomplete proxy for field reliability. The community needs shared protocols that jointly evaluate safety, recovery, intervention rate, and sustained task throughput under shift [Upadhyay et al., 2026, Wu et al., 2026a, Valle et al., 2025].

In particular, evaluation suites should move from single-episode success to *session-level reliability*, including repeated-task stability, failure recovery quality, and operator load over extended runtime.

6.4 Challenge 4: Data Governance and Compute Efficiency

Scaling trends improve capability but increase data, compute, and reproducibility burdens. Efficient adaptation, model compression, and transparent data curation are central for practical adoption [Guan et al., 2025, Yang et al., 2025a, Shen et al., 2026].

Data governance is equally important: licensing, robot-operator privacy, and intervention traceability will increasingly influence which datasets can be reused for large-scale embodied pretraining.

6.5 Challenge 5: Continual Adaptation Under Safety Constraints

Recent post-training results indicate that online adaptation is a major performance driver, but safe adaptation protocols are still immature [Intelligence et al., 2025b, Li et al., 2025b, Lu et al., 2025]. Open questions include:

- how to schedule exploration under hard safety budgets,
- how to integrate teleoperator corrections without destabilizing pretrained priors,
- how to prevent catastrophic forgetting during continual specialization.

6.6 Survey Limitations

This survey focuses on embodied and decision-relevant world modeling within 2024–2026. As a result, broader non-embodied world-model literature is not comprehensively reviewed in the core analysis. We mitigate this with explicit exclusion logging and auditable citation appendices, but taxonomy boundaries in fast-moving subareas (e.g., generalized video world models later adapted to robotics) may evolve with future releases.

6.7 Outlook

We expect the next phase of embodied intelligence to converge on hybrid systems that combine:

- reusable foundation priors,
- decision-coupled world models,
- online adaptation under safety constraints,
- auditable evaluation pipelines tied to real deployment targets.

The strongest near-term gains will likely come from better coupling between predictive modeling and actionable control feedback, while mid-term progress will depend on standardized deployment-centric evaluation and safer continual learning protocols.

7 Conclusion

This survey synthesized embodied AI and world-model research from 2024 to early 2026 under a coupled framework that links system-level embodied decision stacks with model-level dynamics design choices. The central conclusion is that strong embodied performance now depends on explicit coordination among representation, prediction, and control, rather than progress in any single module.

Beyond conceptual synthesis, we provide an auditable citation workflow over 318 collected papers, with 279 in-scope entries under explicit time-window and embodied-closure criteria, plus grouped inclusion and exclusion appendices. This structure is intended to make future updates incremental and reproducible as the field continues to evolve rapidly.

Our overall reading of the current frontier is pragmatic: foundation-scale pretraining has become necessary but not sufficient. Reliable embodied intelligence increasingly requires decision-coupled post-training, representation interfaces aligned with embodiment constraints, and deployment-oriented evaluation protocols that quantify not just task completion, but sustained autonomy quality.

A Full-Coverage Citation Map

A.1 In-Scope Citation Coverage (2024–2026)

This appendix groups all in-scope references by survey bucket and publication year to make coverage auditable.

A.2 agent-architecture

2026 Jian et al. [2026], Li et al. [2026a].

2025 Bai et al. [2025], Bendikas et al. [2025], Corsi et al. [2025], Dey et al. [2025], Fang et al. [2025a], Guo et al. [2025a], Hancock et al. [2025a], Hsieh et al. [2025], Intelligence et al. [2025a], Jabbour et al. [2025], Jang et al. [2025], Li et al. [2025e,f,g], Lin et al. [2025a], Liu et al. [2025b,c], Patratskiy et al. [2025], Pertsch et al. [2025], Pugacheva et al. [2025], Sendai et al. [2025], Song et al. [2025a], Tan et al. [2025a], Turgunbaev [2025], Wang et al. [2025b,c,d], Wen et al. [2025a,b,c,d], Wu et al. [2025], Xiang et al. [2025], Xiong et al. [2025].

2024 Leal et al. [2024], Yang et al. [2024a].

A.3 data-benchmark-eval

2026 Black et al. [2026], Cai et al. [2026], Chen et al. [2026a,b], Hu et al. [2026], Lillemark et al. [2026], Liu et al. [2026a], Magne et al. [2026], Mei et al. [2026], Peng et al. [2026], Ren et al. [2026], Upadhyay et al. [2026], Wang et al. [2026], Wu et al. [2026b,c,a], Xiang et al. [2026], Xie et al. [2026a]. Xie et al. [2026b], Yang et al. [2026], Ye et al. [2026], Yu et al. [2026b], Zhang et al. [2026b,a].

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A.4 foundation-definition

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A.5 planning-reasoning

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A.6 policy-learning

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A.7 survey-meta

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A.8 world-model-core

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2024 Gupta et al. [2024].

B Exclusion Audit Log

B.1 Exclusion Audit

Entries excluded from the main in-scope set are listed by reason. Full row-level details are in `ref/paper_audit.csv`.

B.2 missing_year

Chen et al., Xie, Zhang et al..

B.3 not_embodied_related

Bruce et al. [2024], Savov et al. [2025].

B.4 out_of_window

Ahn et al. [2022], Batra et al. [2020], Bousmalis et al. [2023], Brehmer et al. [2023], Brohan et al. [2023], Chebotar et al. [2023], Dasgupta et al. [2023], Dorbala et al. [2023], Driess et al. [2023], Duan et al. [2022], Fan et al. [2022], Gadre et al. [2022], Gao et al. [2022], Gu et al. [2023], Huang et al. [2023a, 2022a,b, 2023b]. Jiang et al. [2023], Josifoski et al. [2022], Liang et al. [2023], Nottingham et al. [2023], Pugh et al. [2022], Reed et al. [2022], Sarch et al. [2023], Song et al. [2023], Walke et al. [2023], Wang et al. [2023a,b], Wu et al. [2023a,b,c], Xu et al. [2023], Zhao et al. [2023].

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