From Runnable Code to Shippable Applications: Test-Driven Development for Full-Stack Web Application Generation

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1. Introduction

Coding agents can generate web applications from natural-language descriptions, yet a recent study shows that generated applications **fail to meet functional requirements in over 70% of cases** [1].

Test-driven development (TDD) can close this gap, but three challenges block automation for web apps:

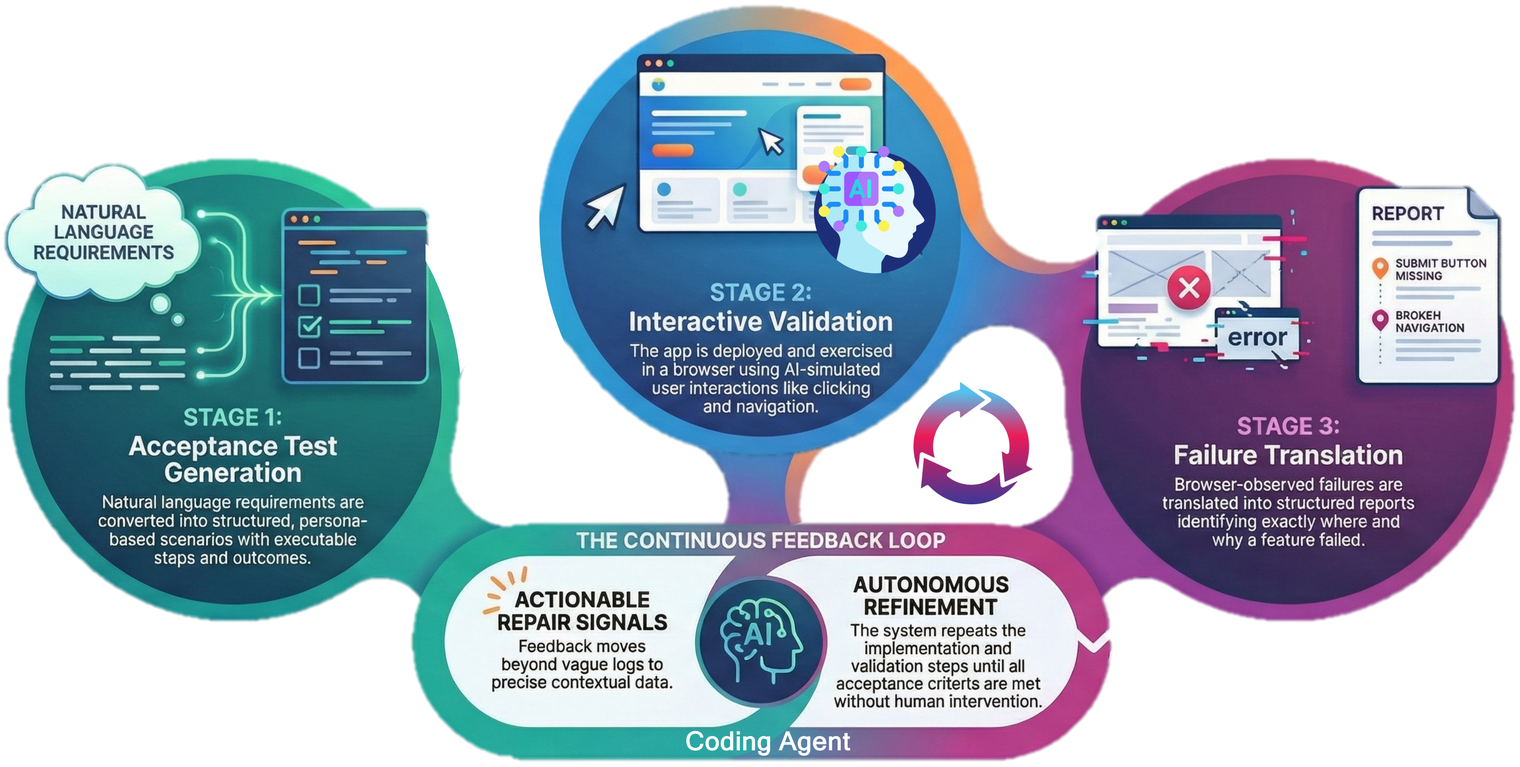
- **Requirement Concretization**: Vague NL descriptions must become executable acceptance tests.
- **Interactive Validation**: Correctness requires browser-based interaction, not just terminal output.
- **Failure Translation**: Browser-observed failures must be converted into actionable repair signals.

We present TDDev, a framework that automates all three steps, enabling coding agents to develop web apps in a closed TDD loop **with zero human intervention**.

2. TDDev Framework

TDDev automates the TDD loop through **three stages**:

- **Stage 1 — Acceptance Test Generation:** Converts NL requirements into structured test cases via persona-driven soap opera testing.
- **Stage 2 — Interactive Validation:** Deploys the app and validates it through a lightweight LLM-backed browser testing agent using Playwright.
- **Stage 3 — Failure Translation:** Converts browser interaction trajectories into structured repair reports for the coding agent.



3. Protocols & Setup

We define four protocols along the **enforcement axis**:

Protocol	Description
Incremental	One feature at a time; bounded deploy–test–repair loop per feature. *High enforcement.*
Whole-Project	Full implementation first; bounded deploy–test–repair over all tests. *Medium enforcement.*
Agentic	Agent has TDD tools but decides when/how to use them. *Low enforcement.*
Non-TDD	No TDD tools; single-pass generation. *Baseline.*

#	Agent	Model	Benchmark
1	ClaudeSDK	Sonnet 4.6	WebGen-Bench
2	ClaudeSDK	Qwen-3.5	WebGen-Bench
3	OpenCode	Qwen-3.5	WebGen-Bench
4	ClaudeSDK	Sonnet 4.6	ArtifactsBench

Metric: $\text{acc@}k = \frac{N_{\text{Pass}} + 0.5 \times N_{\text{Partial}}}{N_{\text{Total}}} \times 100\%$
Each combination runs all four protocols. Attempt budget K=5.

4. Main Results

Combination	Incremental	Whole-Proj.	Agentic	Baseline
ClaudeSDK + Sonnet 4.6	31.5	49.1	**65.8**	31.3
ClaudeSDK + Qwen-3.5	**71.4**	51.4	41.0	23.3
OpenCode + Qwen-3.5	45.7	**50.7**	27.3	11.7
ClaudeSDK + Sonnet (Art.)	81.4	**86.2**	82.9	78.6

TDD infrastructure consistently improves quality: **+34–48 percentage points** over no-TDD baseline across all WebGen-Bench combinations.

5. RQ Answers

- **RQ1 (Module Reliability):** Test generation covers **91.9%** of ground-truth features. Testing agent catches **100%** of defects with zero false positives; residual errors are conservative false negatives.
- **RQ2 (TDD Benefit):** TDD improves quality by **34–48 pp** over baseline across all WebGen-Bench combinations. Benefit scales with task complexity (+7.6 pp on simpler ArtifactsBench).
- **RQ3 (Enforcement Level):** Optimal level depends on generation style. Holistic models → **agentic**; incremental enforcement yields **no improvement**. Conservative models → **incremental**.
- **RQ4 (Feedback Rounds):** Whole-Project doubles accuracy by k=5 (most gains in first two rounds). Incremental stagnates for holistic models but improves for conservative ones (59.7%→71.4%). A single agentic attempt (65.8%) outperforms five enforced rounds for Sonnet.

6. Key Findings

- **Finding 1:** When protocol matches the model's style, TDD **more than doubles** accuracy (Sonnet+agentic: 65.8% vs. 31.3%; Qwen+incremental: 71.4% vs. 23.3%). **Enforcement level is as consequential as model choice.**
- **Finding 2:** Matched configs deliver the largest gains at the lowest cost; mismatched ones produce worst accuracy *and* highest token spend (up to 25×). **Protocol choice is the single largest lever on quality and cost.**
- **Finding 3:** TDDev eliminates all manual intervention, while baseline requires repeated developer attention. **The right metric is unattended fraction, not total time.**

7. User Study & Cost

Three developers used TDDev vs. Bolt.diy:

Method	Manual	Interv.	Prompt
Bolt.diy	4.7 / 15.2 min	3.0	74 words
TDDev	**0.0** / 18.7 min	**0.0**	**0 words**

"It removes the most frustrating part — opening the browser, figuring out what is wrong, and trying to explain it." **— Developer**

Cost efficiency:

Config	Tok. (M)	Δpp
Sonnet + Agentic	5.9	**+36.7**
Sonnet + Increm.	9.7	+0.0
Qwen + Increm.	108.7	**+46.7**
Qwen + Agentic	9.9	+16.7

Conclusions

- TDDev automates TDD for web app generation, closing the runnable–shippable gap.
- TDD improves quality by **34–48 pp** over baseline.
- Optimal protocol depends on model style: holistic → agentic; conservative → incremental.
- Protocol mismatch wastes the entire retry budget (**25**× token cost, 0 pp gain).
- User study: TDDev reduces manual intervention to **zero**.

References

[1] Z. Lu et al. WebGen-Bench: Evaluating LLMs on generating interactive websites from scratch. *arXiv:2505.03733*, 2025.