Universal Robot-Tool Coupling for Construction: A Systematic Review of Cross-Platform Flange Interfaces and End-Effector Adaptation

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Abstract -

Despite the existence of modern capable robots, crews still carry plywood by hand and use nail guns to fasten it on a typical timber-frame job. Panel handling and fastening are obvious candidates for automation because they involve repetitive, labor-demanding tasks that put workers in danger. However, in current practice, the tool on the robot wrist is nearly always connected to a single arm through a unique wiring scheme, bolt pattern, and bracket. It typically takes new hardware, new cable routing, and safety I/O adjustments to move the same end-effector to a different brand of robot or even a different payload class. In this article, we investigate the possibility of having one tool-side interface that can move across several commercial manipulators. We use universal coupling to describe a cross-platform interface that allows the same end-effector to be mounted on different robots with only small mechanical and utility adjustments. To study how realistic this is, we reviewed peer-reviewed reports of robots and end-effectors working together on construction-related tasks. For each manuscript, we noted the mechanical connection, how utilities reach the tool, how well the tool-center point is recovered after re-mounting, and how demanding installation appears. We propose a Universal Coupling Readiness Matrix based on these patterns, which connects mechanical compatibility, utility pass-throughs, TCP (Tool Center Point) stability, and installation effort. We talk about the implications of this approach for the adaptation of a cross-brand tool in robots such as UR, ABB, KUKA, and Yaskawa.

Keywords -

ISO 9409-1 panel handling; timber-frame assembly; automation; validation contexts; interoperability; universal coupling; cross-platform compatibility; tool flange interface; end-effector integration; installation effort; connector; cross-brand adaptation.

1 Introduction

Construction has been one of the most hazardous industries for occupations for a long time. For instance, this industry accounted for nearly 21% of all workplace fatalities in the US in 2023, with falls, slips, and trips accounting for 38.5% of these deaths [1]. Similar trends can be seen in Europe, where approximately 24.0% of fatal workplace accidents in the EU in 2023 were related to construction [2]. Many of these incidents are associated with repetitive, force-intensive tasks performed in unstable environments, like working at heights, handling panels, or fastening elements overhead. Robots could be useful in these types of tasks.

The majority of industrial and collaborative robots come with an end-of-arm tool flange, i.e., an end-effector that complies with ISO 9409-1 [3]. This condition initially implies that tools should be easy to transfer from one arm to another. However, the picture becomes more disjointed when different robots and payload classes are considered. Manufacturers use different centering and keying schemes; therefore, connector layouts and pin assignments are inconsistent [4], and bolt-circle patterns and thread sizes vary. For example, the UR20 flange is specified as EN ISO-9409-1-80-6-M8, but it has different sizes or different screws. In addition, they use a wrist tool-changer to route power, signals, and pneumatics in various ways [5].

For a nailing end-effector, this often turns into new adapter plates, modified hole patterns, re-routed hoses and cables, and changes to safety I/O. The connector choice also sets limits on payload and wrist moments, defines the height and footprint of the stack at the wrist, and influences how repeatable the mounted Tool Center Point (TCP) is. These factors, in turn, affect accuracy, uptime, and risk during on-site operation [5]. As a consequence, an organized and complete analysis of the state of the art is necessary and timely given the increasing complexity and importance of coupling systems in on-site construction robotics.

In this article, a systematic literature review was conducted and a Universal Coupling Readiness Matrix is proposed. This research contribution focuses on the physical couplings that connect construction-oriented robotic arms (manipulators designed or adapted for on-site construction tasks) to end-effectors. Taking into account both the interoperability requirements of coupling technologies and the unique deployment challenges in construction, the review presents a novel analytical viewpoint. According to this perspective, the chosen studies are arranged and categorized to emphasize current interface strategies, validation levels, technological preparedness, and geographic distribution. This synthesis offers a basis for determining important gaps, evaluating maturity trends in connector design, and ultimately inspiring the proposal of a universal robotic coupling system customized for construction requirements. Based on the findings of the systematic review, a matrix is proposed that uses five evaluation criteria to assess possible universal coupling of end-effectors.

For the remainder of the manuscript, "universal coupling" refers to a cross-platform mechanism that includes mounting geometry in compliance with ISO 9409-1 mechanical interface conventions, electrical and pneumatic pass-throughs, and safety signaling [3]. The objective is to maintain stiffness, load capacity, and tool-center-point consistency while attaching the same end-effector to various commercial manipulators, such as those made by UR, ABB, KUKA, and Yaskawa, with only minor modifications.

2 Methodology

The search and screening protocol was designed using PRISMA guidelines [6]. Using that protocol, the literature was then organized according to four practical questions: how to manage mechanical compatibility across brands; how utilities are embedded and routed; how reliably TCP is recovered after re-mount; and how much work installation requires. When combined, the findings show what is already supported by current practice and what technical obstacles remain in the way of a widely reusable coupling for safe and scalable robotic construction.

We conducted a systematic review of the literature following PRISMA 2020 [6] and all records were taken from Scopus. This abstract and citation database was used to retrieve relevant studies. Scopus was selected as the unique database for this systematic review, as it only indexes peer-reviewed journals and conferences with recognized standards. In addition, it allows filtering by year, subject area, document type, language and other metadata, and search strings that facilitate search reproducibility. Moreover, Scopus avoids retrieving preprints, theses, or unreviewed reports, and looks for relevant records; thus, additional databases were not considered. When Scopus redirected to the publisher's site, for example, IEEE Xplore, ASCE, or IAARC/ISARC, those links were used only to access or download the full text. The selected publication time window was 2000–2025. During search and screening, we filtered out subject areas clearly unrelated to the topic (such as Chemistry, Social Sciences, and Health Professions). We kept peer-reviewed journal articles, conference papers, and reviews written in English. The PRISMA flow diagram is illustrated in Figure 1.

We looked at peer-reviewed reports of end-effectors that were actually installed on robots for construction tasks to determine whether such brand-specific issues are rare occurrences or a typical scenario [7]. We excluded research that solely addresses perception, navigation, or high-level control and concentrated on studies that describe the wrist interface and at least the fundamental mounting procedures. Furthermore, we noted the primary interface features and utility routing for every included article, along with its Technology Readiness Level (TRL) and the reported validation setting (bench, lab, relevant environment, or on-site). This keeps the conversation focused on physical coupling and the requirements for a tool to transition between brands.

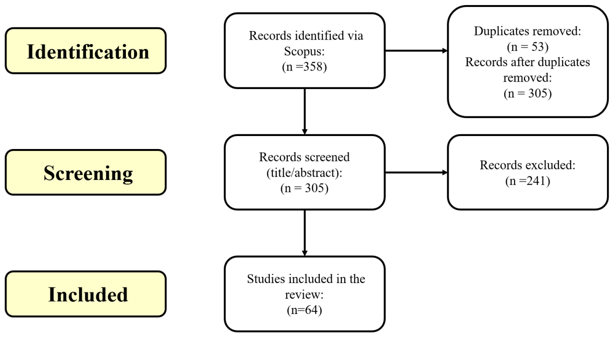

Figure 1. PRISMA flow diagram for literature identification, screening, and inclusion

2.1 Applying PRISMA approach - Two stages

Stage A: Initial Scopus search on on-site manipulation and end-effectors. A structured query was carried out in Scopus to explore relevant research on these topics: *"robotic arm" AND (construction OR build) AND (automation OR automate OR autonomous) AND ("end-effector" OR "end effector").* This search yielded 30 records. After being screened against inclusion/exclusion rules as seen in Table 1, eight studies were retained for the State-of-the-Art database.

Stage A (continued): second Scopus search. A complementary construction-focused query was executed: *("robotic arm" OR "mobile manipulator") AND (construction OR building OR jobsite) AND ("end effector" OR gripper OR "nail gun" OR "vacuum gripper" OR "timber panel") AND (automation OR autonomous.)* Nine of the 34 records found by this search were kept in accordance with the established guidelines.

Stage B: Searches with a focus on universal coupling. A coupling-specific Scopus query was run in order to

Table 1. Inclusion and exclusion criteria used for the systematic review.

Type	Criterion
Inclusion (Track A. Construction robotics)	- English-language peer-reviewed journal articles, reviews, or conference papers (2000–2025). - - Systematic reviews that map on-site construction robotics and technological maturity, or on-site or construction-like context with physical on-arm or platform-mounted end-effector integration.
Inclusion (Track B. Coupling / connector / interoperability)	- English-language peer-reviewed journal articles, reviews, or conference papers (2000–2025). - Robot–tool interfaces, tool changers, modular connectors, calibration frameworks, and Plug & Produce architectures with actual or prototyped mechanical, electrical, and pneumatic interfaces. - Interfaces (power/data transfer, locking/alignment, flange patterns, TCP repeatability) must apply to universal couplings.
Both tracks (A and B)	- Enough methodological information to determine the type of evidence (T/S/I), the validation context (bench, lab, relevant environment, on-site), and the Technology Readiness Level (TRL), following the NASA 1–9 scale, where TRL 1 denotes basic principles observed and TRL 9 represents fully proven systems in operational environments [8].
Exclusion	- Studies focused solely on perception/control with no interface design or physical robot–tool integration. - Opinion/vision papers, non–peer-reviewed sources, theses/dissertations, or items lacking full-text access. - Factory-only automation without relevance to construction-like robot–tool tasks.

specifically target cross-brand interfaces: *“universal coupling” OR “cross-platform interface” OR “cross-brand adapter” OR “universal connector” OR “robot coupling” OR “tool flange” OR “end-effector interface” OR “wrist coupling” OR “robot adapter” OR “modular interface” OR “tool changer” OR “quick coupling” AND (“construction robotics” OR “robotic construction” OR “construction automation” OR “building automation” OR “automated assembly” OR “on-site robotics” OR “industrial robot” OR “robotic manipulator” OR “modular robot”) AND (“end-effector” OR “tool” OR “mount” OR “attachment” OR “integration” OR “ISO 9409-1” OR “flange design” OR “connector”).* Nine of the forty records that this search produced were included.

A complementary Scopus query was then executed: *(”robot modular interface” OR ”robot connector” OR ”tool changing system” OR ”robot tool coupling” OR ”end effector adapter” OR ”standard flange” OR ”ISO 9409” OR ”modular robotics connection”) AND (interoperability OR ”reconfigurable robotics” OR ”hardware standardization” OR ”cross compatibility” OR ”multi robot system”).* This highlighted the lack of research on physical interoperability in robot coupling by returning 1 record that satisfied the requirements and was included.

2.2 Previous Work on the Literature Review

Forward-citation lists for four anchor manuscripts that were already included in Scopus were examined to systematically increase coverage [9]. The following rules, applied in the first part of Stage A, were used for selection:

- *Development of an automation system for steel construction based on robotic crane* — 18 citing records; 5 included.
- *Robotic Insertion of Timber Joints using Visual Detection of Fiducial Markers* — 14 citing records; 3 included.
- *Automated Object Manipulation Using Vision-Based Mobile Robotic System for Construction Applications* — 34 citing records; 6 included.
- *Robotic Automation System for Steel Beam Assembly in Building Construction* — 27 citing records; 4 included.

Also as previous work, two conference papers from the same research program were added as Direct Prior Work because they focused on the development of the end-effector that motivated this review and are directly related to interface universality:

- *Implementation of a Robotic Manipulator End Effector for Construction Automation*
- *Advances in the Development of a Custom End Effector for Construction Automation*

As part of the ongoing project, both were already accessible. The protocol register was updated with their inclusion and justification. Thus far, stages A and B and their complementary queries generated 29 duplicate records in the combined Scopus export across all queries and forward-citation expansions. In addition, 163 distinct records were left for title-abstract screening after duplicates were eliminated, and 47 of those eventually satisfied the eligibility requirements. The extra hits discovered during reruns were either obviously outside the scope of Table 1 criteria or duplicates of previously screened records. Therefore, 47 studies were included in the synthesis.

For every included study, a standard template was used to record the year, title, authors, contribution/innovative elements, results, T/S/I tag, validation approach, TRL (1–9), opportunity areas/possible proposal/differentiation/future work, category (1–6: Control/Planning; Specialized Components; Vision/Sensing; Direct Prior Work; General-Purpose Platforms; Survey/Review), and number of citations, as shown in Table 2.

The T/S/I tag, which stands for Theory (conceptual or analytical work), Simulation (numerical or digital experiments) and Implementation (physical prototype with empirical results), indicates the type of evidence used in the study. From TRL 1 (basic principles) to TRL 9 (proven system ready to be placed on the market), TRL adhered to the NASA 1–9 framework [8], which was interpreted for construction robotics (lab validation ≈ TRL 4, relevant-environment validation ≈ TRL 5–6, on-site prototype ≈ TRL 7, qualified/completed systems ≈ TRL 8–9).

2.3 Supplementary Literature Review

To identify potentially relevant articles that might have been missed among the 47 selected, synonyms were used in the search strings, and combinations were made with

Table 2. Data-extraction schema (fields to capture for each of the 64 studies).

Field	Description
Year	Publication year of the study.
Title	Full title of the article or conference paper.
Authors	Main authors as reported in the publication.
Contribution / Innovative elements	Short summary of what the paper proposes and what is technically new.
Results	Key findings and any performance metrics that have been reported.
T/S/I	Type of evidence used in the study: Theory (T), Simulation (S), and/or Implementation (I).
Validation	The process of testing the method and confirming its accuracy (e.g., bench tests, lab mock-ups, relevant-environment trials, or on-site experiments).
TRL (1–9)	The adapted NASA 1–9 scale for construction robotics is used to determine the technology readiness level [8].
Opportunity / Proposal / Differentiation / Future work	Short summary of the gaps, suggested paths, distinctive features, and future work that should be done.
Category (1–6)	Classification into one of six categories: Control/Planning; Specialized Components; Vision/Sensing; Direct Prior Work; General-Purpose Platforms; Survey/Review.
Citations (count)	At the time of data extraction, the number of citations in Scopus.

queries in stages A and B. To remain aligned with robot-tool coupling, this supplementary literature search focused on robot-mounted tools (interfaces, changers, tool flanges, interoperability), end-effector (integration, exchange systems), and robotic handling and assembly applications. The result consisted of four proposed search strings that were used to perform four independent searches in Scopus. The search queries, the articles returned by them, and the documents selected after the screening effort (as in Table 1) are included as follows:

- *("construction robotics" OR "robotic construction" OR "construction automation") AND ("robotic arm" OR "robotic manipulator" OR "mobile manipulator" OR cobot) AND ("end effector" OR gripper OR tool)* – Three articles selected from 21 records yielded from the query.
- *(construction OR building OR jobsite OR "on site" OR onsite) AND ("robotic arm" OR "robotic manipulator" OR "mobile manipulator") AND (plywood OR panel OR timber OR steel OR drywall OR block) AND ("end effector" OR gripper OR fastening OR nailing OR assembly)* – Four manuscripts chosen from 79 records retrieved from the search string.
- *("universal coupling" OR "cross-platform interface" OR "cross-brand adapter" OR "universal connector" OR "robot coupling" OR "tool flange" OR "end-effector interface" OR "wrist coupling" OR "robot adapter" OR "modular interface" OR "tool changer" OR "quick coupling") AND ("construction robotics" OR "robotic construction" OR "construction automation" OR "building automation" OR "on-site robotics" OR "automated assembly" OR "robotic manipulator" OR "industrial robot" OR "mobile manipulator") AND ("end effector" OR tool OR mount OR attachment OR integration OR "ISO 9409" OR flange OR connector)* – Three documents were added to the study from the 28 records returned by the query.
- *("robot tool interface" OR "end effector interface" OR "tool changer" OR "tool changing" OR "quick changer" OR "quick coupling" OR "robot coupling" OR "wrist coupling" OR "tool flange" OR "robot adapter" OR "end effector adapter" OR "universal connector" OR "cross platform interface" OR "cross brand adapter" OR "tool flange calibration" OR "detachable gripper") AND (robot OR robots OR manipulator OR manipulators OR cobot OR cobots) AND ("end effector" OR "end effectors" OR tool OR tools OR gripper OR grippers OR flange OR flanges OR connector OR connectors OR coupling OR couplings) AND (interoperability OR modular OR reconfigurable OR "plug and produce" OR "semantic OPC UA" OR calibration)* – Seven manuscripts selected from 37 records retrieved from the search string.

As a result of this complementary search, 17 documents were added to the study for a total of 64 manuscripts to be considered in Results and Discussion. The dataset with all 64 records is publicly available under a CC BY-NC 4.0 license [10]. We considered this search strategy to be sufficient given the limited focus on on-site construction robotics and physical robot-tool coupling, as well as the fact that Scopus indexes the major robotics and construction venues from which the included publications were drawn [11].

3 Results and Discussions

The final synthesis covered 64 peer-reviewed studies published between 2000 and 2025 that: (1) reported robotic tasks relevant to construction, and (2) sufficiently detailed the robot-tool interface including coupling information. This included mechanical mounting and at least a rudimentary explanation of system integration and utilities. A brief reality check reveals that although the literature on construction robotics is expanding rapidly, there is a lack sufficient description of the wrist interface in a way that allows for useful portability analysis. When determining whether a coupling approach can be practically applied across various robot platforms, it is important to consider what is actually documented in the literature, such as how the TCP is recovered after removing and re-mounting a tool or how safety and I/O are integrated.

The publication record for this cohort is sparse in the early years, but increases rapidly after 2020. The highest number of studies appears in 2024 and 2025, meaning that a large portion of usable evidence comes from this recent period. Beyond sheer volume, the mix of publication types

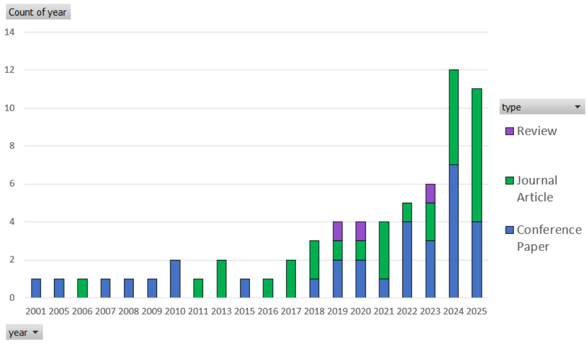

Figure 2. Studies per year stacked by publication type

has shifted: early work mostly appears in conference proceedings, while the last two years show a much stronger presence in journals. This reflects the field's move from initial demonstrations to more detailed and rigorous reporting. The timing also matters because most of what we can say about cross-brand portability is based on a very recent set of studies, rather than decades of standardized practice. A visual approach to this explanation, showing: type of publication, year of publication, and manuscripts per year is available in Figure 2.

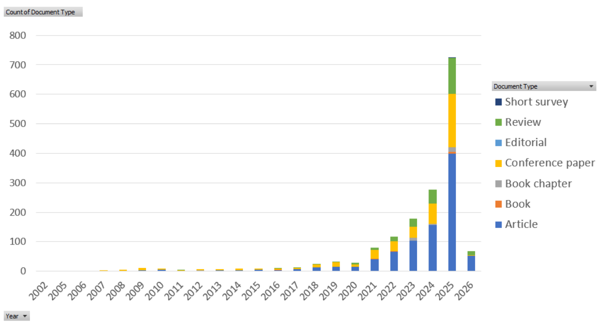

Figure 3. Citations to all publications in Figure 2 per year, and by document type

Figure 3 shows the impact that the publications in Figure 2 have had on the research work related to end-effectors, their adapters, and couplings in robotic arms within construction processes. After 2020, the distribution of Scopus citations increases even more sharply, reaching extremely high annual volumes by 2024-2025. The majority of citation records are journal articles, and conference papers comprise a significant share of the following journals. Compared to the smaller subset of studies that met the inclusion criteria and provided adequate detail on the wrist interface, it is clear that many published works still lack interface-level detail for coupling assessment. Furthermore, there is a lack of papers that adequately describe the wrist stack so that transferability between robots can be assessed without completely redesigning the flange.

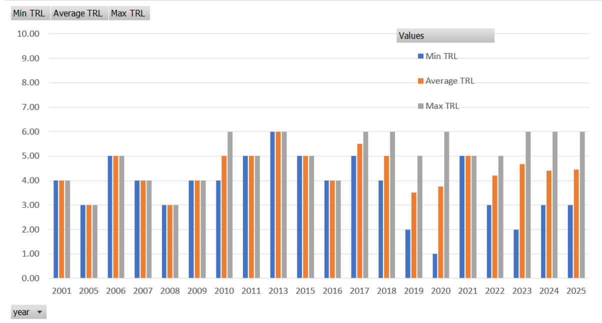

Figure 4. TRL over time

Another useful perspective comes from the Technology Readiness Level (TRL) distribution over time. In Figure 4, it can be seen that since 2001, the overall maturity of studies has varied over time. When a topic grows quickly, early-stage exploration and mid-stage prototyping often appear side by side. Since only a small number of studies advance to on-site deployment and the majority stay at laboratory or relevant environment validation, this limited level of maturity is particularly crucial for universal coupling. The coupling design becomes crucial at this point. If utilities need to be rerouted every time a tool is moved to a different robotic arm, Tool Center Point (TCP) repeatability after re-mounting is ignored, or safety wiring is treated as a one-time setup, then a tool may work in a controlled environment but remain difficult to deploy in commercial settings.

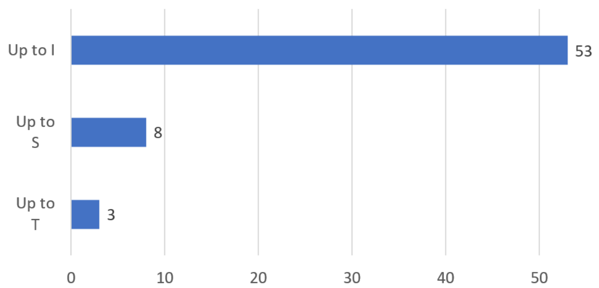

Figure 5. Validation summary of included studies, categorized as theoretical analysis (T), simulation (S), and physical implementation (I).

The evidence shows that this field goes beyond purely conceptual work. Many studies combine theory with simulation, and a significant number also include physical prototypes (see Figure 5). Although this achievement is encouraging, it reveals a practical limitation: most implementations are tightly integrated with a specific robot. In addition, the interface that would allow an end-effector to be easily remounted, serviced, or transferred across different robot platforms is often insufficiently described and rarely standardized.

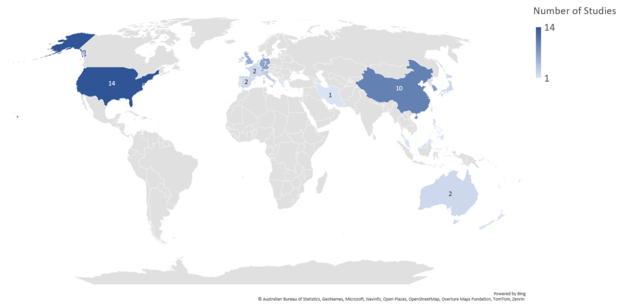

Figure 6. Geographic distribution heat map. Number of articles in Scopus database.

Another important element to consider is that research activity is geographically concentrated in a small number of countries, as seen in Figure 6. These few clear leaders are mainly three countries: The United States, China, and South Korea. With a smaller contribution are Switzerland, England, Germany, and Australia. Furthermore, there are contributions from other countries, but they have one or two scientific publications indexed in Scopus.

The overview presented in the previous paragraph matters for interoperability. Different regions and application domains tend to rely on different robot manufacturers, wrist connector conventions, and tool-changing ecosystems. As a result, interface solutions developed in one setting often carry implicit assumptions that do not translate well to others, such as expectations about available pneumatic feed-throughs at the wrist, preferred connector families, or safety I/O practices. From the perspective of universal coupling, this points away from designing for a single reference robot and toward designing around a shared set of constraints that can hold across multiple robotic ecosystems.

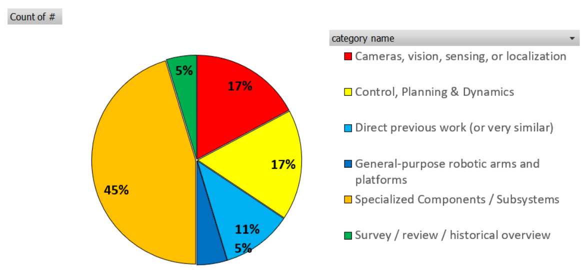

Figure 7. Category distribution across the six-class scheme

The distribution of robotic arm research categories oriented towards construction activities highlights where the most current effort is focused (Figure 7). A large share of the literature addresses specialized components and vision or sensing, with control and planning also well represented. In contrast, work on general-purpose platforms and survey or review studies remains relatively limited. This imbalance helps explain why cross-brand coupling is still an open issue: much of the community's effort is devoted to improving perception, planning, and execution, whereas far fewer studies treat the wrist interface as a reusable platform layer. In practice, however, this layer often determines whether a new tool remains a one-off demonstration or evolves into a capability that can be transferred across systems.

All presented results point to a consistent interpretation. The field is expanding rapidly and producing a large number of prototypes, but the observed maturity plateau and reporting practices suggest that wrist-level integration remains a recurring limitation. Although ISO 9409-1 offers a common mechanical reference, it does not address many of the practical factors that govern portability in construction contexts. These include alignment and keying variations, connector layouts and pin assignments, utility routing strategies, safety signal integration, flange stack height and stiffness, and the ability to reliably recover the TCP after tool removal and re-installation. Within this body of work, these challenges appear frequently enough to be understood as systematic barriers rather than isolated implementation details.

This drawback motivates the introduction of a universal coupling proposal. The evidence does not indicate that the main gap is the absence of additional task-specific end-effectors. Instead, it shows that many end-effectors remain effectively locked to a single robot integration because the coupling layer is custom, time-consuming to reproduce, and rarely validated for repeatability. A Universal Coupling Readiness matrix follows naturally from these observations, as it translates recurring barriers into concrete and testable dimensions.

4 Proposed Universal Coupling Concept

The findings of the previous section demonstrate that portability in construction robotics typically fails on the robot's wrist rather than the task logic. Moving the same tool between different robot brands typically results in a lot of rework, including new adapter plates, new bolt patterns, rerouting cables and hoses, re-pinning connectors, and modifications to safety I/O systems, even when the end effectors and the tools function well. In order to minimize all that rework, this section suggests a universal coupling concept that divides what must remain brand-specific from what can be standardized at the tool level.

The main idea is to use a two-part system. The robot-side module handles the differences between robot families, such as flange size, bolt patterns, centering/keying methods, available utilities on the wrist, connector layouts, and payload limits. The tool-side module, on the other hand, remains the same and stays attached to the end-effector across different robot platforms. The interface between these two parts is designed to be a consistent mechanical connection, with a protected handoff for utilities, so re-mounting the tool does not require reinventing the whole integration process each time. The proposed conceptualization is depicted in Figure 8.

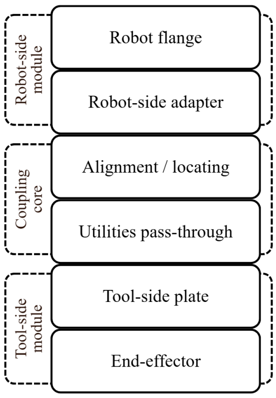

Figure 8. Conceptual universal coupling stack diagram

The idea behind this proposal has mechanical advantages. It uses ISO 9409-1 as a starting point for the bolt circle design, but it does not rely only on the bolt circle to ensure a repeatable mount. In-stead, the system includes alignment features that control both movement and rotation during assembly, like dowel pins that fit precisely or a kinematic-style locating method. These features handle repeatability, so the bolt pattern mainly serves to clamp and transfer load, rather than finding the center. This condition helps prevent any drift in the TCP after removing and reinstalling the tool, without the need for time-consuming recalibration or manual adjustments.

A key component of the introduced coupling is the provision of utilities. Instead of using temporary connections, the proposal uses a protected pass-through for power, I/O, communications, and pneumatic supply and exhaust. Robots have different wrist configurations, so those details remain on the robot-side module, while the tool-side maintains a consistent manifold and connector. In addition to keeping fasteners, alignment features, and connectors accessible for field service, the coupling is stiff and compact to minimize wrist moments during tasks such as panel handling and fastening.

A brief list of design specifications directly derived from the patterns found in the literature can be used to summarize the suggested concept.

1. Cross-platform mechanical fit via interchangeable robot-side adapters without modifying the tool-side mounting.
2. Repeatable locating through explicit alignment features to reduce TCP shift after re-mounting.
3. Protected utilities handoff for power, signals/I/O, and (when needed) pneumatics, avoiding one-off routing and re-termination.
4. Low installation burden with a short, tool-accessible assembly sequence and clear strain relief.
5. Stiff and compact load path to control stack height and wrist moments during panel handling and fastening.
6. Safety integration awareness, so safety-related wiring and interlocks can be handled consistently across platforms.

This section intentionally stays at the architecture level. The point is not to claim a finished hardware design, but to define a coupling structure that matches the failure modes that keep showing up in practice, repeatability loss, utility rework, and installation effort, and to make those targets concrete. The next section turns that idea into a Universal Coupling Readiness Matrix so existing systems can be compared consistently, and an implementable connector design can be guided by clear criteria.

5 Universal Coupling Readiness Matrix

The universal coupling concept was explained at the architectural level in the previous section, which also identified the interface points that consistently cause issues when teams attempt to transfer a tool between robotic brands. The difficulty of synthesis comes from inconsistent reporting of those same points in the literature. Although some studies primarily report task performance and leave the wrist interface unclear, others describe how the tool was mounted, routed, and re-mounted.

To provide a simplified evaluation system for interface readiness, a Universal Coupling Readiness Matrix is proposed, as seen in Table 3. It employs five categories and a straightforward scale of 0-2. A score of 1 indicates that the aspect is addressed but is still platform-specific or lacking, a score of 2 indicates that the study offers specific features or procedures that would likely facilitate reuse, and a score of 0 indicates that the dimension is not reported or not specified in detail. The matrix does not imply that all published papers can be scored consistently; it is meant to organize the synthesis and act as a guide for future coupling work.

Table 3. Universal Coupling Readiness Matrix

Dimension	0 (Not reported / not specified)	1 (Partial or platform-specific)	2 (Explicitly supports reuse)
Mechanical interface	Mounting approach not described in usable detail, or a one-off bracket with no locating strategy.	Adapter/mount is described but tied to one robot family; locating is implied or unclear.	Reusable mounting approach with an explicit locating strategy (e.g., pins/keying or defined locating scheme).
Utilities interface	Utilities not described, or routing is external with no defined handoff.	Utilities are present but transfer would require retermination or major rerouting per robot.	Defined tool-side handoff with clear robot-side mapping or adapter approach; routing is protected and repeatable.
TCP after re-mount	TCP recovery after tool removal and re-mount is not specified.	Alignment/calibration is mentioned, but repeatability is only implied or sensitive to installation variation.	TCP consistency after remount is addressed explicitly, measured or constrained by the locating scheme.
Safety and I/O	Safety/I-O integration not specified in usable detail.	Safety/I-O is described for one platform, but transfer likely requires substantial rework.	Safety/I-O handoff is described in a portable way that reduces cross-platform rework intent.
Installation workflow	Installation steps not described, or workflow appears complex and difficult to repeat.	Workflow is partially described; effort appears moderate and service access is limited.	Clear, repeatable workflow with practical access for mounting, re-mounting, and service.

6 Conclusions

The systematic literature review demonstrates the rapid developments in end-effector integration and construction robotics, but it also highlights a persistent bottleneck in the robot wrist area. Although many systems are successful at the task level, moving the same tool to a different brand of robot still frequently requires custom integration. Even when the end-effector design is robust, deployment is often slowed by the need to rebuild or rework adapter geometry, utility routing, connector selections, and safety I/O.

When reuse is feasible, five interface requirements regularly appear in included studies: a repeatable mount that is independent of the bolt pattern, a protected hand-off for utilities, consistent TCP following removal and re-mount, safety and I/O that do not require significant platform redesign, and an installation workflow that can be repeated in field conditions. These patterns enable a two-part universal coupling that preserves a compact and stiff wrist structure while separating robot-side variations from a stable tool-side interface. For uniform reporting, these dimensions could be compiled into a proposed Universal Coupling Readiness Matrix.

The fact that the records were retrieved from the SCOPUS database could be somewhat restrictive. Future reviews could increase coverage by including additional databases, patents, and other indexing sources. Strict like-for-like comparisons may be hampered by inconsistent reporting of wrist-interface details across publications. Future research should prototype and test a universal coupling across various robotic platforms using useful metrics with reporting details that facilitate comparison and replication.

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