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DEVELOPMENT OF AN AUTOMATED ELECTRICAL MATERIAL QUANTITY ESTIMATION SYSTEM

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Abstract: **Electrical material estimation for residential building projects is commonly performed by interpreting consultant-provided computer aided design (CAD) drawings, manually extracting quantities, selecting project-specific materials, and preparing a commercial quotation. Repeated counting, measurement, data entry, and recalculation make the conventional workflow slow and expose the estimator to missed items and arithmetic errors. This paper presents a CAD-driven automated electrical material quantity estimation system designed primarily for residential villas and apartments. The proposed workflow accepts DWG and DXF drawings, extracts relevant CAD entities, applies consultant-specific symbol and layer mappings, detects configured electrical elements, and produces a quantity takeoff for engineering verification. The verified quantities are linked with owner-specified brands and material quality levels, while labour is evaluated using point-based rates and other project costs are incorporated through a configurable estimation engine. The system finally produces a structured bill of quantities and a detailed quotation. A human-in-the-loop verification stage is deliberately retained so that automation accelerates repetitive work without removing engineering judgment. The proposed architecture is intended first for controlled internal use by an electrical estimation engineer and can later be extended toward broader commercial deployment. The contribution is a practical bridge between conventional 2D CAD estimation and a traceable, reusable digital estimation workflow.**

Index Terms—**Electrical estimation, CAD, DWG, DXF, quantity takeoff, symbol mapping, bill of quantities, cost estimation, quotation automation, electrical contracting.**

I. INTRODUCTION

Electrical quantity estimation is a key commercial activity in building projects because the estimate determines the material requirement, labour allowance, project cost, and ultimately the contractor's quotation. In the conventional workflow considered in this study, the estimation engineer receives an electrical CAD drawing from the owner or consultant and manually identifies points, counts symbols, measures relevant routes, enters quantities into calculation sheets, selects materials, and prepares the quotation. The project source material identifies this sequence as repetitive and time-consuming and notes that missed symbols, incorrect quantities, and calculation errors can influence project cost and profitability.

The proposed system is motivated by a practical contractor-side requirement: a quotation must be prepared quickly enough to respond to competitive tenders while still preserving sufficient accuracy to avoid avoidable losses. Existing research on automated quantity takeoff similarly identifies manual intervention as a major source of time and error, while automated approaches seek to convert design information into structured quantities for downstream estimating activities [1]–[4]. The present work differs in its focus on electrical contracting from conventional 2D residential CAD drawings and on the commercial chain from detected quantity to brand-specific material selection, labour, transportation, profit treatment, and quotation generation.

A further characteristic of the target environment is repeatability. Residential drawings from established consultants often follow stable layer structures, block

definitions, and symbol conventions. Rather than requiring a new interpretation for every drawing, the proposed system stores these relationships in a consultant profile. The source project specifies that a configured consultant profile can be reused on subsequent projects, reducing repeated setup and supporting consistent quantity extraction.

The main objectives are therefore: 1) reduce manual quantity extraction from residential electrical CAD drawings; 2) provide reusable consultant-specific symbol mapping; 3) maintain an engineer verification step for reliability; 4) associate verified quantities with owner-selected material brands and quality levels; 5) automate material, labour, transport, and profit calculations; and 6) generate a detailed, consistent quotation from the approved estimate.

II. RELATED WORK AND RESEARCH GAP

Computer-aided and model-based quantity takeoff has been investigated for several decades. Early work on automated quantity surveying demonstrated the value of linking CAD information with local data sources for bill-of-quantities preparation and highlighted the need for faster and more effective estimation methods [1]. Later BIM oriented studies showed that structured model information can support automatic extraction of construction quantities, although the reliability of automated results depends on the semantics, classification, and quality of the underlying model [2], [3].

Zhao et al. developed an automated quantity takeoff approach in which classification information and derived-quantity rules are preloaded and used to transform model information into an estimating database [2]. Taghaddos et al. similarly explored API-based automation for systematic quantity extraction from BIM models and compared automated outputs with conventional calculations [3]. More recent work has introduced explicit quantity-precision checking and data validation mechanisms to improve the reliability of automated takeoff [4]. These studies establish that automation can reduce repetitive work, but they also indicate that automation is strongly dependent on how design information is represented.

A knowledge-model approach proposed by Liu et al. addressed semantic variation and measurement rules in automated BIM quantity takeoff [5]. Akanbi et al. also examined the challenge of developing interoperable quantity-takeoff algorithms across different modeling workflows [6]. These findings are important to the proposed CAD based system because a 2D drawing does not inherently guarantee a universal semantic meaning for every symbol. Consequently, the proposed method does not assume that a graphical shape alone is sufficient; it combines layers, blocks, symbols, coordinates, and consultant-specific mapping.

Recent research has also investigated automation directly from traditional 2D documents using information extraction and rule-based reasoning, showing the continuing relevance of non-BIM workflows [7]. The research gap addressed in this paper is therefore not simply automated quantity counting. The proposed system integrates 2D CAD interpretation with contractor-oriented estimation logic: consultant profile reuse, engineer verification, owner-specific brand selection, point-based labour, transportation, profit treatment, BOQ generation, and quotation preparation. This end-to-end workflow is particularly suited to residential electrical contracting where the same consultant drawing conventions can recur across projects.

III. PROPOSED SYSTEM ARCHITECTURE

The proposed architecture is organized as a sequence of controlled processing stages rather than a single opaque prediction module. The input is a consultant-provided electrical drawing in DWG or DXF format. The CAD processing stage extracts drawing entities and converts them into structured records. A consultant profile then maps recognized blocks, layers, and symbols to electrical categories. The detection stage identifies configured components and stores their locations. Quantity takeoff converts detections into category-wise counts or measurable quantities. The estimation engineer reviews the results before the system proceeds to material selection and costing. Finally, the quotation generator produces a structured commercial document. The overall sequence follows the block structure defined in the project source.

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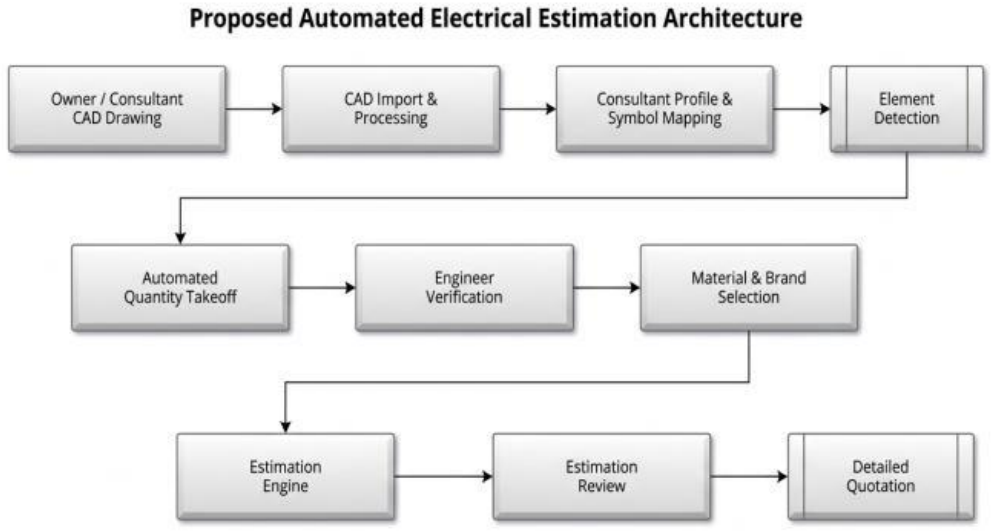


Fig. 1. Proposed end-to-end architecture of the automated electrical estimation system.

IV. CAD DATA ACQUISITION AND PROCESSING

The proposed system supports both DWG and DXF because these are common CAD exchange formats in the target workflow. Autodesk describes DWG as the native drawing format used by AutoCAD-based products, while DXF provides a tagged representation of drawing information. The source project also explicitly specifies DWG and DXF as the input formats.

For DXF processing, the system can inspect structured sections and graphical entities, including blocks, layers, and entities. Autodesk documentation notes that DXF organizes drawing information through sections such as TABLES, BLOCKS, and ENTITIES, and that graphical entities can be associated with coordinates and other attributes.For DWG, a suitable CAD-processing component or conversion layer is required because the native format is not equivalent to plain-text DXF. The architecture therefore separates file decoding from the estimation logic: regardless of source format, the downstream modules should receive a common internal representation of drawing objects.

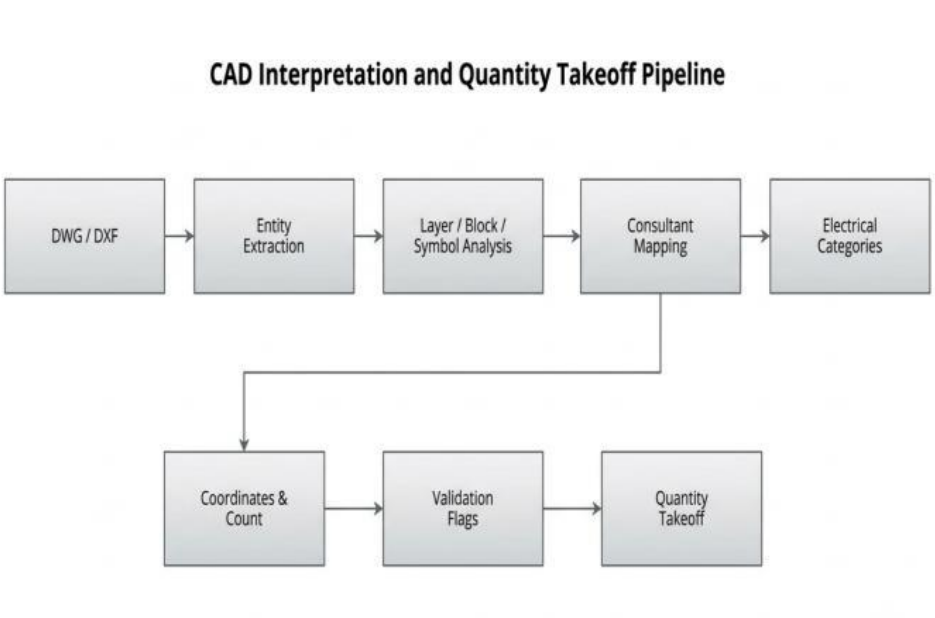


Fig. 2. Proposed CAD interpretation pipeline from drawing file to structured quantities.

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The internal representation should retain at least entity type, layer name, block or symbol identifier where available, insertion coordinates, geometric properties, text attributes, and drawing-unit information. Retaining these attributes is important for traceability. When a component is detected, the system should be able to point the estimator back to its drawing location instead of presenting only an unexplained numerical total.

V. CONSULTANT-SPECIFIC SYMBOL MAPPING

A major design feature is the consultant profile. Different CAD authors may use different block names or layer names for visually similar electrical components. In the target business environment, however, established consultants tend to reuse drawing conventions. The proposed system therefore allows an administrator to configure a mapping once and store it as a reusable profile. For example, a particular block or layer combination can be mapped to LIGHT_POINT, FAN_POINT, SOCKET_POINT, AC_POINT, or DISTRIBUTION_BOARD.

The mapping engine should support more than a single identifier. A robust rule can be represented as a combination of layer, block name, entity type, optional text attribute, and geometric condition. A confidence or status field can also be retained so that the engineer can identify detections requiring attention. The mapping record may be represented as:

Mapping Rule = {Consultant ID, Layer, Block/Symbol ID, Entity Type, Electrical Category, Rule Status}

Once a profile has been validated, the same rules can be applied to future projects from that consultant. The source project specifically proposes this reuse to reduce configuration time and improve consistency. This approach is preferable to attempting universal symbol recognition at the first prototype stage because it exploits the controlled drawing environment of the target contractor.

VI. ELECTRICAL ELEMENT DETECTION AND QUANTITY TAKEOFF

The detection module uses the configured mapping rules to classify electrical objects. The initial residential scope includes light points, fan points, socket outlets, air-conditioning points, distribution boards, and other categories that are explicitly configured. The coordinates of recognized elements are retained so that the engineer can visually cross-check detections against the original CAD drawing.

For point-based items, the quantity is obtained by counting validated detections in each category. For measurable routes, such as conduit or cable runs, the system may calculate geometric lengths when the drawing contains sufficiently reliable route information and the required estimation rules are available. The project source treats such length calculation as conditional on adequate drawing information and predefined rules rather than as an unconditional guarantee. This distinction is important for technical credibility because a 2D CAD line does not automatically reveal the complete installed cable length unless routing conventions and measurement rules are known. $Q_k = \Sigma n_{i,k}$ for point category k

$L_k = \Sigma$ length($r_{i,k}$) for a measurable route category k

The quantity takeoff database should retain category, quantity, unit, source entities, and drawing coordinates. This allows an item to be traced from the final BOQ back to the original drawing. Such traceability is particularly important when the estimator is comparing automated quantities with an existing manual estimate.

VII. HUMAN-IN-THE-LOOP VERIFICATION

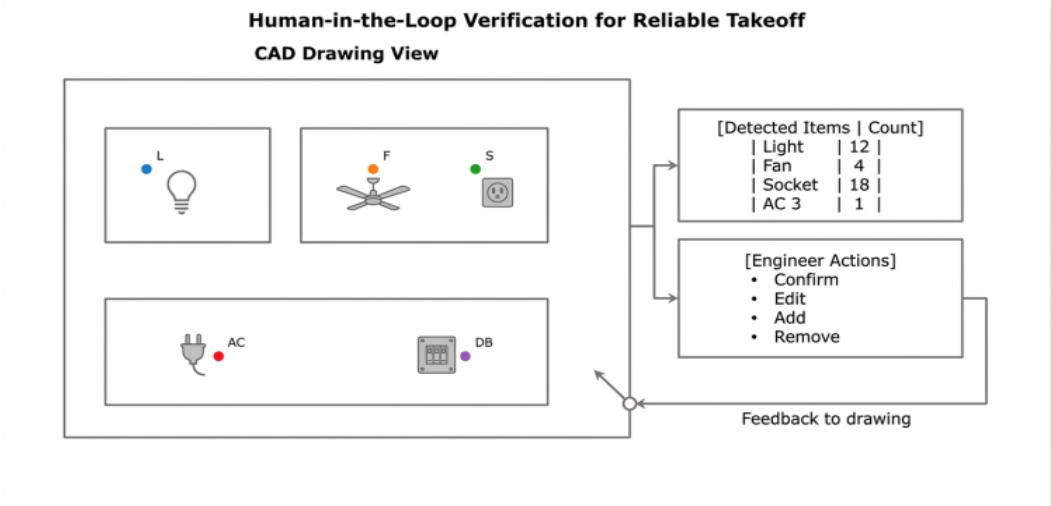


Fig. 3. Engineer verification interface concept: detected items remain linked to their CAD locations.

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The proposed system intentionally does not remove the estimation engineer from the process. Instead, it automates repetitive extraction and reserves engineering judgment for validation. The verification interface should highlight detected symbols and display category-wise quantities. The estimator must be able to confirm, edit, add, or remove detections. The source project identifies this stage as a mechanism for correcting missing, duplicated, or wrongly classified components before costing.

This architecture also creates an opportunity for continuous improvement. When an estimator corrects a detection, the correction can be logged and reviewed by an administrator. Repeated corrections from the same consultant can be converted into improved mapping rules. Thus, the system can become more accurate through controlled rule refinement without requiring an immediate machine-learning model.

A useful validation record should contain the automated quantity, corrected quantity, correction type, user, timestamp, and drawing reference. This makes the system auditable and provides the dataset required for later evaluation of precision, recall, and processing time.

VIII. MATERIAL SELECTION AND BRAND MANAGEMENT

Electrical material selection is not independent of the owner. The owner may specify a particular brand, product series, or quality level, and the quotation must reflect those requirements. The proposed system therefore separates quantity extraction from material selection. After quantities are verified, the estimator chooses the applicable material database entries. The project source defines standard, premium, and luxury options and associates each entry with brand, model or series, unit, and rate.

A material master can be represented as Material = {Category, Brand, Series, Tier, Unit, Unit Rate, Effective Date, Active Status}. The tier is only a convenience for predefined alternatives; an owner-specific brand can override the default tier without changing the detected quantity. This separation is important because changing a switch brand should update the price and quotation description, but should not change the number of switch points detected from the CAD drawing.

The initial database can cover the contractor's frequently used residential categories, such as wires, switches and sockets, distribution boards, protective devices, conduits, boxes, and accessories.

Additional categories can be introduced after the internal prototype is validated.

IX. ESTIMATION AND COST COMPUTATION

The estimation engine combines verified quantities, selected material rates, point-based labour rates, transportation, and profit treatment. The project source identifies this engine as the core computational stage and specifies material cost, labour, transportation, and profit margin as its principal inputs.

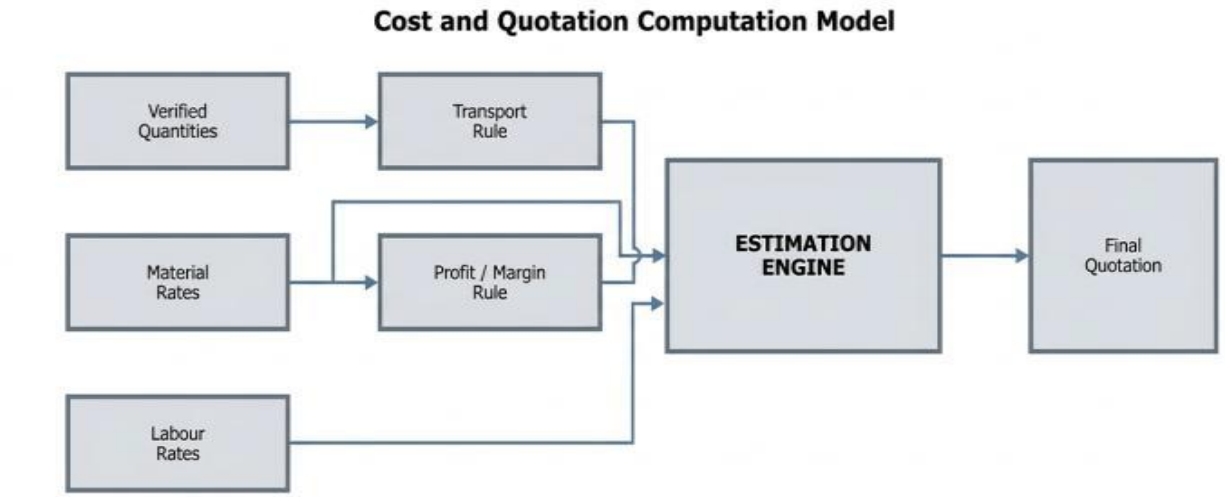


Fig. 4. Cost-engine structure linking verified quantities, rates, overhead inputs, and quotation value.

For a material item i, the material cost is:

$$C_material = \Sigma (Q_i \times R_i)$$

where Q_i is the verified quantity and R_i is the selected unit rate. For point-based labour, the labour component can be represented as:

$$C_labour = \Sigma (P_j \times L_j)$$

where P_j is the number of points or activities of type j and L_j is the corresponding labour rate. Transportation may be configured as a fixed amount or as a rule-based value. If profit is implemented as a markup m on cost, the quoted value is:

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$$C_{quote} = C_{material} + C_{labour} + C_{transport} + (m \times C_{base})$$

where C_{base} is the sum of the cost components before profit. If the business instead specifies a true gross-margin percentage g of the selling price, the mathematical treatment is different: $C_{quote} = C_{base}/(1-g)$. The software should therefore label the selected profit method explicitly to prevent the common confusion between markup and margin.

The system should also preserve rate versions and effective dates. A quotation generated using an older rate card must remain reproducible even after rates are updated for a new project. This is important for commercial auditability.

X. BILL OF QUANTITIES AND QUOTATION GENERATION

After calculation, the system organizes the result into a Material Bill of Quantities (BOQ). Each line should contain item description, category, brand, series or specification, quantity, unit, unit rate, and amount. Labour, transportation, and profit should be presented separately or according to the contractor's established quotation format. The source project specifies that the final quotation can contain customer and project information, material descriptions, brands, specifications, quantities, unit rates, labour, transportation, total amount, and terms and conditions.

A quotation template should be configurable rather than hard-coded. The contractor should be able to maintain company identity, address, tax or registration information where applicable, payment terms, validity period, exclusions, warranty language, and approval fields. The estimator should not need to retype these details for every tender.

The final output should be generated as a consistent PDF document. A project revision number and quotation date should be stored with the estimate. This supports comparison between revisions when a consultant issues an updated drawing.

XI. SOFTWARE IMPLEMENTATION CONCEPT

The first implementation is intended as a private web application for an office estimation engineer. A browser-based interface allows the contractor to centralize material rates, consultant profiles, user permissions, and quotation templates while keeping the application accessible from office workstations. The system can be organized into five logical services: authentication and project management; CAD processing; mapping and quantity extraction; estimation and material database; and quotation generation.

The user interface should follow the estimator's existing workflow. A project is created with client and consultant details, the CAD file is uploaded, the applicable consultant profile is selected, detected quantities are reviewed, materials and brands are selected, costing is calculated, and the final quotation is approved. The interface should expose the calculation path rather than hiding it. Each total should be expandable to show its source quantities and rates.

Role-based access is recommended. An estimation engineer can create and revise estimates and generate quotations, while an administrator can maintain material rates, labour rates, consultant profiles, quotation templates, and minimum commercial rules. This separation reduces the probability that an estimator unintentionally changes a company-wide rate.

The architecture is deliberately modular so that a future Windows desktop version can reuse the same quantity and cost-engine logic. Commercial expansion to offices, shops, and larger projects should be treated as a later phase rather than being mixed into the initial residential implementation.

XII. VALIDATION METHODOLOGY

No numerical performance result is claimed in this paper because the prototype has not yet been experimentally benchmarked. Instead, the proposed validation protocol compares the automated system against completed manual estimates prepared by the company's estimation engineers. A representative set of residential villa and apartment projects should be selected, with drawings from the consultants for whom mapping profiles are available.

For each project, the following measurements should be recorded: manual estimation time, automated processing time, automated quantity, verified quantity, final manual cost, final software cost, number of corrections, and number of missed or falsely detected components. Point categories should be evaluated separately because a system can perform well for block-based points while requiring more intervention for route-based quantities.

Useful evaluation measures include quantity precision, quantity recall, absolute percentage deviation, processing-time reduction, and quotation-value deviation. For a category k:

$$Precision_k = TP_k / (TP_k + FP_k)$$
$$Recall_k = TP_k / (TP_k + FN_k)$$
$$APE_k = |Q_{auto,k} - Q_{ref,k}| / Q_{ref,k} \times 100$$

Here TP, FP, and FN represent correctly detected, falsely detected, and missed items respectively, while Q_{ref} is the engineer-verified reference quantity. These measures provide a more meaningful evaluation than claiming a single overall accuracy value. The engineer verified quantity should be treated as the reference for the initial pilot, and later field records can be used to evaluate whether the estimate remains commercially reliable.

A second validation stage should test quotation revisions. The same project should be recalculated after changing a material brand or tier. The expected result is that material

cost and quotation value change while the CAD-derived quantity remains unchanged. This test verifies that the quantity and pricing layers have been correctly separated.

XIII. EXPECTED CONTRIBUTIONS

The proposed system contributes a practical contractor-oriented workflow for converting residential 2D electrical CAD information into a verified estimate and quotation. Its principal contributions are:

1) consultant-specific mapping that exploits repeated CAD conventions; 2) traceable electrical element detection with coordinate based verification; 3) separation of quantity, labour, material, and commercial calculations; 4) owner-driven brand and specification selection; 5) configurable transport and profit treatment; and 6) automated BOQ and quotation generation.

The approach is also designed to preserve human accountability. Instead of presenting automation as a replacement for the estimation engineer, it uses automation to remove repetitive counting and arithmetic while retaining professional verification. This is particularly appropriate for an internal contractor workflow in which the cost of a missed item can be directly reflected in project profitability.

XIV. LIMITATIONS AND FUTURE DEVELOPMENT

The initial system is limited to residential electrical drawings and to electrical categories for which reliable consultant-specific mapping rules are available. It does not assume that every possible CAD symbol can be interpreted universally. Cable and conduit lengths may require additional drawing conventions and estimation rules. Drawings containing inconsistent blocks, exploded symbols, missing layer information, or unusual drafting practices may require manual intervention.

Future development can extend the system to commercial projects, multi-floor coordination, more advanced route measurement, automated circuit inference, additional low-current systems, and learning-based symbol recognition. A Windows desktop version can be developed after the web prototype has been validated internally. Historical corrections can also form a controlled dataset for machine learning assistance, but such methods should complement rather than replace deterministic mapping and engineer verification in the early product stages.

XV. CONCLUSION

This paper presented an automated electrical material quantity estimation system designed around the practical workflow of residential electrical contracting. The proposed method begins with consultant-provided DWG or DXF drawings, extracts structured CAD information, applies reusable consultant-specific symbol mappings, detects electrical elements, and produces a quantity takeoff for engineer verification. Verified quantities are then linked to owner specified materials and brands, while point-based labour, transportation, and profit rules are applied through a configurable estimation engine. The final output is a structured BOQ and detailed quotation.

The central design principle is controlled automation: repetitive and arithmetic-intensive activities are automated, while the estimation engineer remains responsible for reviewing the detected quantities before commercial approval. This provides a path toward faster quotation preparation without treating automation as infallible. The proposed architecture can therefore serve as a practical foundation for an internal office tool and, after measured validation on real projects, as a scalable commercial product for other electrical contractors.

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