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Vishvakarma Foundry AI: A Low-Cost AI-Assisted Framework for Preliminary Gating and Riser Design in Sand Casting

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Abstract - Foundry gating and riser design strongly influences mould filling, turbulence, air entrainment, shrinkage control, casting yield and the final soundness of sand cast components. In small and medium foundries, the early-stage design of sprue, runner, ingate and riser dimensions is frequently performed using manual formula-based calculations, while advanced simulation packages may remain difficult to use for every preliminary design because of cost, training requirements and infrastructure limitations. This paper presents Vishvakarma Foundry AI, a low-cost AI-assisted and offline-capable framework for preliminary gating and riser calculation. The system combines geometry-based volume estimation, Bernoulli-based choke area calculation, a configurable gating-ratio method, riser-volume estimation, a web interface with pattern selection, a backend chatbot using Gemini API support, a clipboard-based fallback mechanism and an Arduino-type hardware demonstrator with keypad and LCD output. The calculation workflow was checked against a manual quality-assurance workbook covering representative foundry components such as gears, pulleys, bearings, valves, pipe fittings, pump components and engine parts. Project documentation indicates that the proposed workflow can reduce preliminary calculation time from approximately 5 hours in a traditional manual method to approximately 10 minutes for supported cases. The contribution of the work is not to replace full casting simulation, but to create an accessible first-pass engineering assistant for students, MSME foundries and early design screening.

Keywords: Foundry automation; gating system; riser design; sand casting; AI-assisted calculation; Arduino prototype; MSME digitization

1. INTRODUCTION

Metal casting remains an essential manufacturing process for producing complex engineering components that are difficult or uneconomical to manufacture by machining alone. In sand casting, the gating system forms the flow path through which molten metal travels from the pouring basin into the mould cavity. A typical gating system includes a pouring basin, sprue, runner, ingate and related flow-control regions; a riser or feeder is used to compensate for volumetric shrinkage during solidification. Improper design can result in turbulence, oxide formation, air entrapment, sand erosion, misruns, shrinkage cavities and poor casting yield. Therefore, the first-pass design of the gating and risering system is a critical activity even before detailed simulation or physical trials are performed.

Conventional gating design involves repeated arithmetic, interpretation of foundry rules, and decisions regarding pouring time, discharge coefficient, sprue height, gating ratio and safety margin. Experienced foundry engineers often perform these calculations quickly, but students and small workshops may need several iterations to obtain consistent dimensions. Modern CAE software can analyze mould filling and solidification in detail, but such tools require licensing, user training, appropriate hardware and project-specific setup time. This creates a practical gap between manual calculation and advanced simulation.

The present work addresses this gap by converting standard preliminary calculation logic into a structured digital workflow. The objectives are integrated into the system design: support common pattern families, compute casting volume and gating parameters, reduce repetitive manual effort, present outputs through both a web interface and an offline hardware demonstrator, provide beginner-friendly explanation through an AI chatbot, and verify arithmetic consistency using a manual QA calculation set.

The work is intended as an early-stage engineering assistant rather than a substitute for foundry expertise or final production validation.

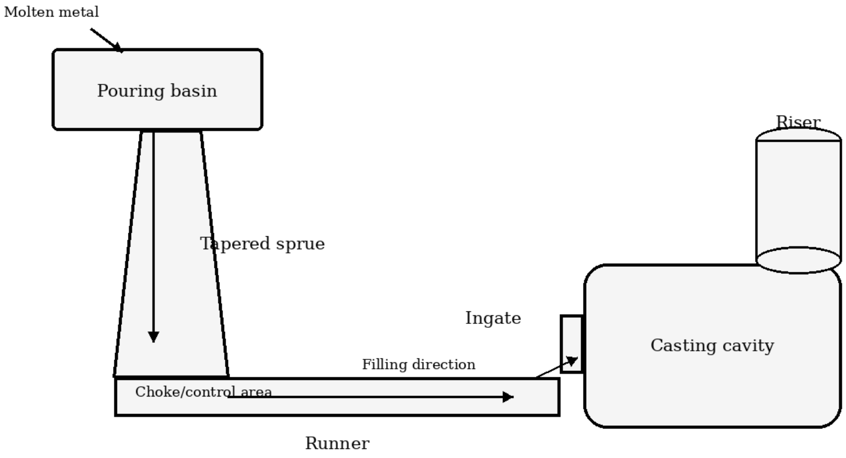


Fig 1 : Schematic representation of a basic sand-casting gating system used as the conceptual basis for the calculation workflow.

1.1. Literature survey

Research on gating design generally focuses on reducing defects by controlling metal velocity, limiting turbulence and improving the relationship between gating geometry and casting quality. Iqbal discussed gating design criteria for sound casting and emphasized that turbulence, incomplete filling, porosity, mould erosion and slag/dross entry are strongly connected to poor gating practice [1]. Jezierski, Dojka and Janerka optimized steel-casting gating systems using Campbell-based principles and numerical modelling, showing that conventional arrangements may produce excessive flow velocity and internal defects, while optimized arrangements improve flow control [2]. Recent work on sand-casting gating design has similarly reported that redesigning the sprue, runner and ingate geometry can improve productivity and quality by reducing turbulence and defect formation [3].

A second group of studies uses CAE tools such as MAGMASOFT, ProCAST, ANSYS, Inspire Cast and Click2Cast to predict filling behavior, solidification, shrinkage tendency and hot spots [4-6]. These approaches are valuable for production-level validation, but they may not be available at the preliminary design stage in small foundries or educational laboratories. The uploaded project literature comparison identifies this accessibility issue as the main research gap: existing work demonstrates optimization methods, but often depends on software, skill and infrastructure that many MSME foundries cannot afford for routine first-pass calculations.

Table 1: Literature-based research gap and response of Vishvakarma Foundry AI.

Work / area	**Main contribution in literature**	**Position of proposed work**
Iqbal, 2014	Rules for sound gating design; defect mechanisms such as turbulence and incomplete filling.	Converts rule-based understanding into a guided calculation sequence.
Jezierski et al., 2018	Computer modelling and Campbell-based optimization for steel castings.	Provides a low-cost first-pass layer before expensive simulation is used.
Edlabadkar et al., 2025	Empirical gating redesign for sand-casting quality and productivity.	Automates repeated redesign calculations for student and MSME use.
Simulation-based studies	CAE prediction of flow, hot spots, shrinkage and yield improvement.	Uses formula-based screening when CAE is not available or is too slow for early iterations.
Present work	Accessibility, offline use, AI explanation and multi-component QA checking.	Combines web, backend, AI fallback and microcontroller output in one preliminary tool.

2. PROPOSED CALCULATION AND AUTOMATION FRAMEWORK

2.1. Overall system approach

The proposed framework is organized around a sequential calculation path. The user first selects a component family or pattern type and enters dimensions. The volume module calculates the pattern volume. The gating module then estimates gate/choke area using a Bernoulli-type flow relation, followed by sprue and runner sizing according to a selected gating ratio. A riser-volume estimate and total metal volume are generated to support yield evaluation. The output can be presented as a web result, an AI-explained response or an LCD result on the offline demonstrator.

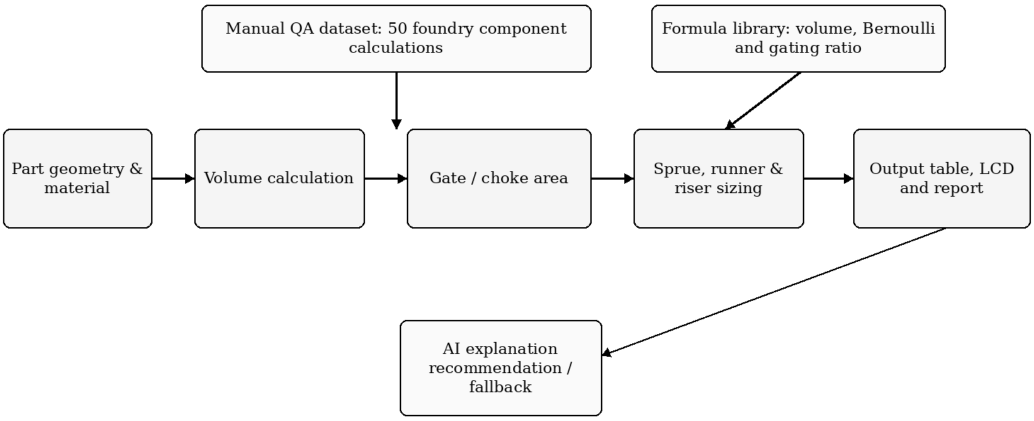


Fig 2 : Proposed calculation workflow linking input geometry, formula modules, QA verification, output and AI explanation.

2.2. Pattern selection and frontend concept

The frontend design sketches supplied with the project show a pattern-configuration interface with options such as cube, cylinder, sphere, cone, torus/ring and hexagonal prism. The sketches also include a live 3D-preview concept in which the user can see the selected geometry before completing the calculation. This approach is important for educational users because geometry selection is one of the most common sources of error in manual volume calculation. A student who incorrectly selects a solid shape instead of a hollow shape may obtain wrong gating dimensions even if the later formulas are correct.

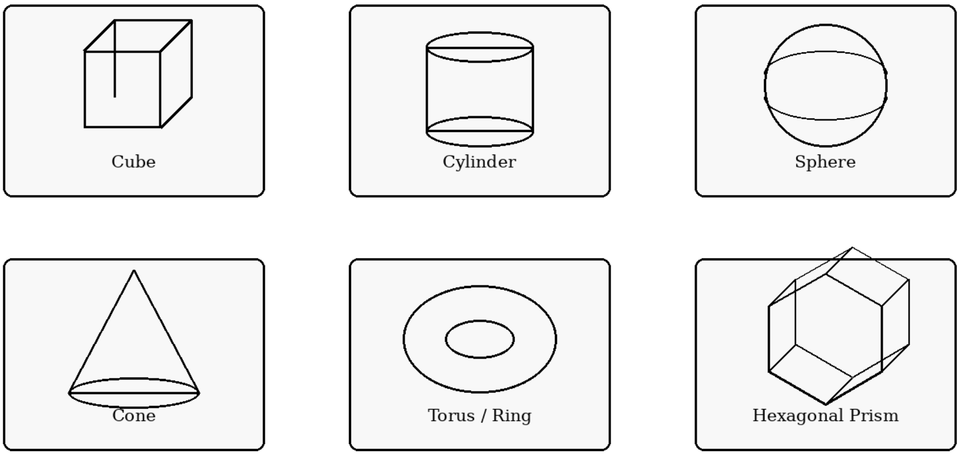


Fig 3 : Cleaned pattern-library representation derived from the frontend configuration sketches.

2.3. Formula structure used in the preliminary calculation

The calculation engine is based on a preliminary design philosophy. It does not solve the Navier-Stokes equations or replace solidification simulation. Instead, it standardizes the arithmetic that is repeatedly performed during early gating design. Depending on the selected pattern, the volume is calculated using the relevant geometric relation. For example, a hollow cylindrical or ring-like geometry may be calculated using Eq. (1).

$$V = (\pi / 4) (D^2 - d^2) h \qquad (1)$$

where V is component volume, D is outer diameter, d is bore or inner diameter and h is height or face width. For thin-wall or combined shapes, the total volume is obtained by adding or subtracting component volumes according to the part geometry.

$$A\_g = V\_p / \{t\ C\_d \sqrt{(2\ g\ h\_s)}\} \qquad (2)$$

where A_g is gate or choke area, V_p is pattern volume or pour volume used in the design stage, t is pouring time, C_d is discharge coefficient, g is gravitational acceleration and h_s is effective sprue height. The manual workbook supplied with the project repeatedly uses a gating ratio of 2 : 1.5 : 1. Therefore, the sprue area A_s and runner area A_r are computed using Eq. (3), while the riser volume is approximated using Eq. (4).

$$A\_s = 2\ A\_g, \quad A\_r = 1.5\ A\_g \qquad (3)$$

$$V\_r = 0.15\ V\_p, \quad V\_total = V\_p / Y \qquad (4)$$

Here V_r is riser volume and Y is the assumed casting yield. In the QA examples, a yield value close to 0.833 is used in several cases. These ratios and coefficients are treated as configurable engineering assumptions; a production-ready implementation should allow foundry-specific calibration.

Table 2: Formula structure used for preliminary gating and riser calculations.

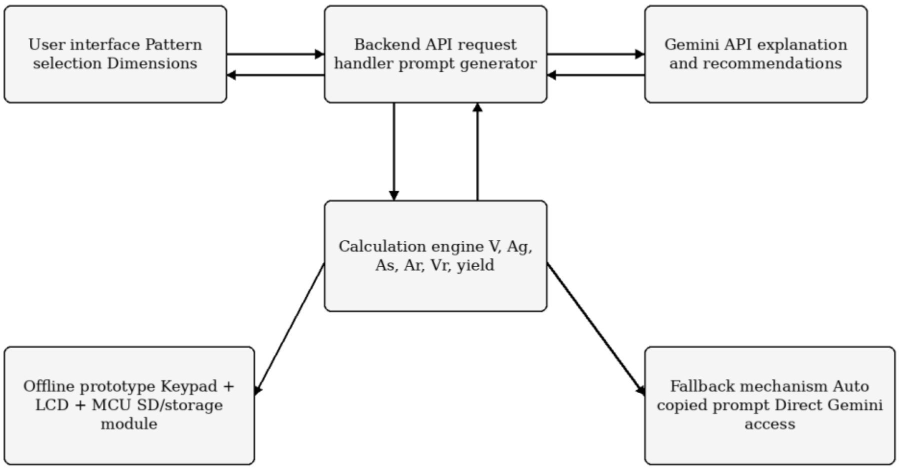
Module	**Calculation basis**	**Output**
Geometry module	Cube, cylinder, sphere, cone, torus/ring, hollow and combined shapes	Computes part or pattern volume
Flow module	Bernoulli-based relation with pouring time, coefficient and sprue height	Computes gate/choke area
Gating-ratio module	2 : 1.5 : 1 in the project QA examples	Computes sprue and runner area
Riser module	V_r = 0.15 V_p as used in manual examples	Estimates feeder volume
Yield module	V_total = V_p / Y	Estimates total molten metal requirement

3. IMPLEMENTATION

3.1. Web-backend and AI guidance layer

The backend documentation describes a Gemini API integration system for an AI chatbot. In the intended workflow, the user enters dimensions and obtains calculated values. The backend prepares a structured prompt containing the calculated volume or gating results, attaches the API key at the server side and sends the request to the AI service. The response is returned to the user as an explanation or recommendation. The chatbot is used as an explanatory layer: it can describe what the calculated values mean, identify practical checks and guide beginners through the result.

Because free or student-level API usage may face rate limits, temporary failures or server downtime, the project includes a fallback mechanism. When the chatbot response is unavailable, the interface can open direct Gemini access. The generated prompt is automatically copied to the clipboard so the user can paste it and continue the explanation process. This backup strategy is useful during demonstrations because the calculation result is not blocked by a temporary API failure.

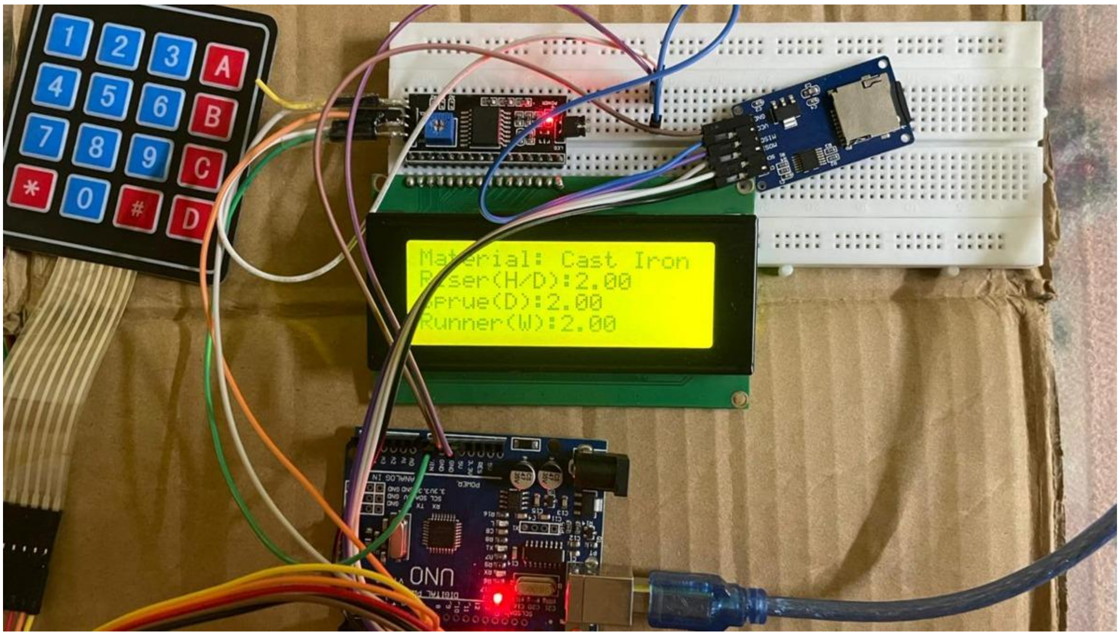


Hybrid architecture supports web-based calculation, AI guidance and a shop-floor demonstrator.

Fig 4 : Web-backend, AI-guidance and offline-prototype architecture of Vishvakarma Foundry AI.

3.2. Offline hardware prototype

The hardware demonstrator proves that the concept can operate beyond a laptop-only workflow. The uploaded prototype photograph shows a keypad, LCD, microcontroller board, breadboard wiring and an SD/storage module. The LCD displays material and computed output values such as riser, sprue and runner dimensions. This demonstrator is important for foundry environments where a compact shop-floor device may be preferred over a full web application, especially for educational demonstrations or small workshops with limited infrastructure.



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Material: Cast Iron
Riser(H/D):2.00
Sprue(D):2.00
Runner(W):2.00
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Fig 5 : Offline hardware prototype showing keypad input, LCD output, microcontroller board and storage module.

3.3. Functional modules

Table 3: Functional modules implemented or planned in the proposed system.

Module	**Role**	**Engineering value**
Input module	Accepts dimensions, material selection and pattern family.	Reduces repeated manual entry and organizes data.
Calculation engine	Performs volume, gate, sprue, runner, riser and yield calculations.	Creates a fast first-pass gating design.
Frontend visualization	Displays pattern options and planned 3D preview.	Improves learning and avoids geometry-selection mistakes.
AI chatbot layer	Explains calculated values and suggests practical checks.	Supports beginners and documentation.
Fallback layer	Copies prompt and opens direct Gemini access when API call fails.	Improves reliability during demonstrations.
Hardware layer	Keypad + LCD + microcontroller demonstrator.	Supports offline and shop-floor usage.

4. MANUAL QA DATASET AND CALCULATION RESULTS

4.1. Manual calculation dataset

The manual calculation workbook supplied with the project contains 50 representative examples. It includes gears, pulleys, bearing components, valves, elbows, pipe junctions, pump casing, impeller, engine block, cylinder head, piston, flywheel and bracket-type components. The value of this dataset is not only the numerical output; it also shows the repeated structure of the calculation. This repeated structure makes the project suitable for automation because the same formula sequence can be applied after changing the geometry and dimensions.

Selected cases from the manual workbook are standardized in Table 4. The values are rounded to two decimal places because handwritten calculations and unit conversions may use intermediate rounding. The examples demonstrate that the software target is not a single classroom shape, but a practical family of mechanical foundry components.

Table 4: Selected manual QA examples used to check the calculation workflow.

Component	**V (cm^3)**	**A_g (cm^2)**	**A_s (cm^2)**	**A_r (cm^2)**	**V_r (cm^3)**	**V_total (cm^3)**
Spur gear	220.89	18.41	36.82	27.61	33.18	265.17
Helical gear	292.31	24.36	48.72	36.54	43.85	350.91
Bevel gear	299.90	24.98	49.96	36.54	≈45.00	360.02
Worm gear	835.55	61.18	122.36	91.77	125.33	1003.06
Worm wheel	1809.55	88.34	176.68	132.51	271.43	2172.33
Rack and pinion	225.00	18.76	37.52	28.14	33.75	270.11

4.2. Time reduction and usability result

The project business document compares the time required for preliminary gating calculation. The traditional manual method is estimated at about 5 hours, an existing complex software workflow at about 2 hours and Vishvakarma Foundry AI at about 10 minutes for supported preliminary cases. On the basis of these values, the proposed workflow reduces the time from 300 minutes to 10 minutes, which corresponds to a reduction of approximately 96.7 percent relative to the manual method.

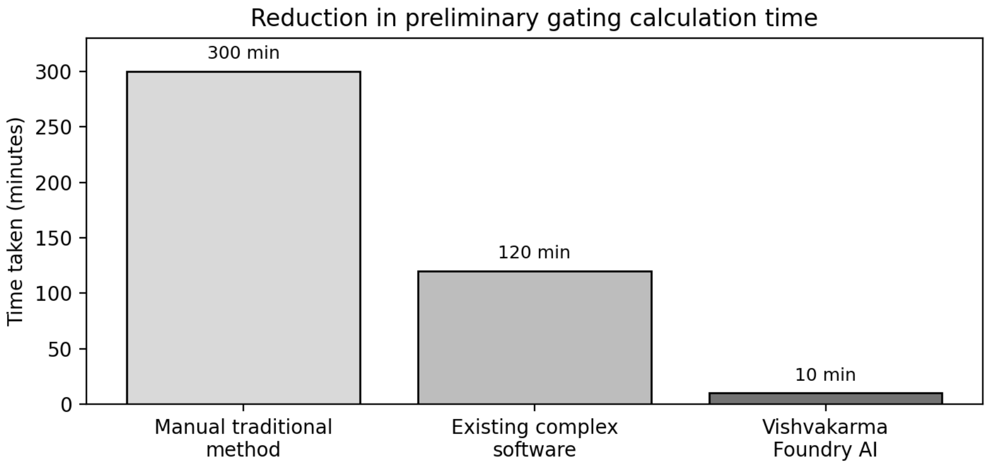

Fig 6 : Reported reduction in preliminary gating calculation time for supported cases.

Table 5: Time comparison for preliminary gating calculation.

Method	**Reported time**	**Minutes**	**Interpretation**
Traditional manual method	5 hours	300 min	Baseline
Existing complex software	2 hours	120 min	Requires setup and skilled use
Vishvakarma Foundry AI	10 minutes	10 min	Approx. 96.7% faster than manual calculation

5. DISCUSSION

The main contribution of Vishvakarma Foundry AI is accessibility. The system translates formula-based gating design into a guided workflow that can be used by students and small foundries during early design. The manual dataset demonstrates that many foundry components follow a repeatable sequence: calculate volume, estimate gate area, apply gating ratio, estimate riser volume and evaluate total molten metal requirement. Automating this sequence can reduce arithmetic errors and free the user to focus on design interpretation.

The system should be compared with simulation tools carefully. Simulation software provides deeper physical analysis, including mould filling patterns, cooling, solidification, hot spot prediction and defect visualization. Vishvakarma Foundry AI is not designed to replace this level of analysis. Its strength lies in rapid screening, calculation consistency, teaching and low-cost deployment. For critical castings, the output should be reviewed by a foundry expert and followed by simulation, pilot pouring and defect inspection.

Industry-facing feedback received through the IIF Students Chapter context supports this positioning. The feedback suggested that the AI-assisted gating calculation work could be shared with industry, used for student-industry discussion and treated as a TRL 1-2 activity suitable for further pilot review. This indicates that the work is best described as a proof-of-concept and early engineering demonstrator, not a finished industrial certification tool.

6. BUSINESS AND DEPLOYMENT RELEVANCE

The project business model positions the system as a combined software and hardware opportunity. The proposed revenue structure includes SaaS subscription, hardware device sales, custom integration and training or setup. The document estimates an Indian foundry opportunity of more than Rs 500 crore and a global opportunity of more than Rs 5000 crore, based on the large number of foundries and manufacturing units that may need affordable automation. These values are project-level estimates and should be validated through pilots, customer interviews and adoption studies.

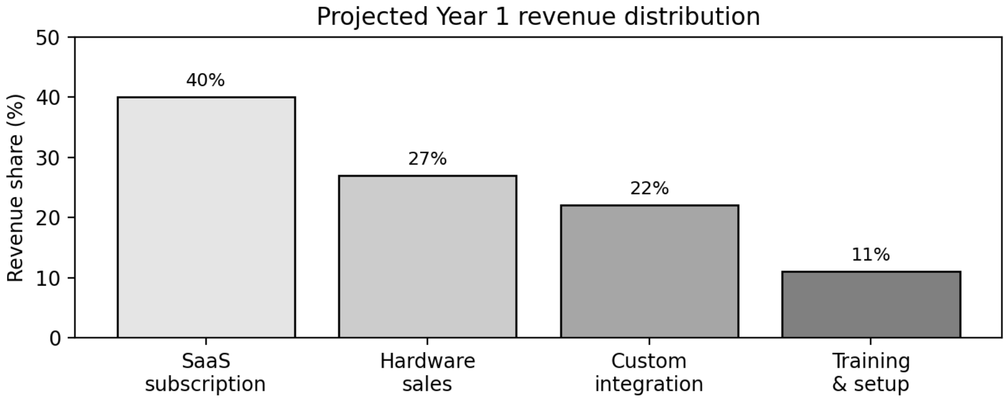

Fig 7 : Projected Year 1 revenue distribution from the project business model.

Table 6: Deployment and commercialization elements proposed in the project business model.

Element	**Indicative model**	**Purpose**
SaaS subscription	Rs 4,999 to Rs 50,000+ per month	Recurring revenue and scalable software deployment
Hardware device	Rs 18,000 to Rs 35,000 one-time	Offline shop-floor calculator for small foundries
Custom integration	Project-based	Integration with existing foundry workflow or ERP/CAD tools
Training and setup	Additional service revenue	Student workshops, foundry onboarding and operator training

7. LIMITATIONS AND FUTURE WORK

The present system uses preliminary equations and project assumptions. Therefore, the accuracy of the output depends on the selected coefficient, pouring time, sprue height, gating ratio, yield assumption, material properties, mould condition and geometry simplification. A production version should allow these parameters to be calibrated for each foundry and material. The hardware prototype should also be ruggedized for shop-floor conditions, and the web interface should be tested with foundry users for usability.

Future work should include experimental casting trials, comparison with CAE simulation, defect inspection before and after design changes, calibration of gating ratios for different materials and addition of more complex geometries. The AI layer should be trained or prompted with verified foundry rules, and its response should clearly distinguish between calculated values, assumptions and practical recommendations. A structured pilot with industrial partners would allow the current TRL 1-2 concept to move toward a validated prototype.

CONCLUSION

This paper presented Vishvakarma Foundry AI, an AI-assisted and offline-capable framework for preliminary gating and riser design in sand casting. The work combines geometry-based volume estimation, Bernoulli-based gate-area calculation, gating-ratio rules, riser estimation, web-backend implementation, chatbot explanation, clipboard fallback and a microcontroller-based display prototype. The manual QA workbook demonstrates the repeated calculation structure across a wide range of components, while the time comparison indicates a substantial reduction in preliminary design effort for supported cases. The proposed framework fills an accessibility gap between slow manual calculation and advanced simulation software. Its most appropriate use is as a first-pass engineering assistant for students, MSME foundries and early design screening, followed by expert review, simulation and casting trials for production-critical parts.

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