

Training Pathways for Vocational Undergraduate Talent in Drone-based Inspection of Historic Buildings under the Low-altitude Economy

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Abstract

The low-altitude economy is expanding the educational significance of unmanned aircraft systems from a narrow technical skill to a field-specific professional capability. In historic-building conservation, drone-based inspection can improve visual access, image documentation, defect recording and digital modelling. However, these functions require graduates who understand both the cultural logic of heritage protection and the operational logic of unmanned aircraft. This paper develops a vocational undergraduate training pathway for drone-based inspection talent in historic-building conservation. Drawing on recent literature on unmanned aerial vehicle (UAV) photogrammetry, digital heritage, work-based learning and vocational undergraduate education, the study proposes a closed-loop model. This model links policy and job-task demand, competency profiling, modular curriculum design, project-based implementation, evidence portfolios, and iterative assessment. Three design tables specify competency indicators, curriculum hours and assessment weights; two figures visualise the training pathway and the proposed distribution of learning hours and assessment evidence. The paper argues that vocational undergraduate programmes in architectural design should not simply add drone operation as an isolated skill module. Instead, they should build an integrated pathway in which heritage cognition, flight safety, image acquisition, photogrammetric processing, defect interpretation, report writing and professional ethics are trained through staged projects. The proposed model provides a transferable framework for architecture-related vocational undergraduate programmes seeking to connect low-altitude economy opportunities with local heritage conservation services.

Keywords

Low-altitude economy, Vocational undergraduate education, Historic-building conservation, Drone inspection, Unmanned aerial vehicle photogrammetry, Project-based learning

Introduction

The growth of the low-altitude economy has made unmanned aircraft systems (UAS) a visible part of logistics, emergency response, agriculture, tourism and urban governance. In China, the low-altitude economy has also become a policy keyword associated with new productive forces, digital infrastructure and local industrial upgrading. Official reports indicate rapid market expansion, while aviation authorities have strengthened the regulatory basis for civil unmanned aircraft operation and identification [1]. For education, this policy environment has a direct implication: Drone operation can no longer be treated only as a hobby-like skill or a stand-alone technical certificate. It is becoming a professional capability that must be embedded in

specific occupational scenarios.

Historic-building conservation is one such scenario. Conservation work increasingly depends on image-based documentation, three-dimensional survey, condition assessment and preventive monitoring. Close-range and aerial photogrammetry have become accessible tools for recording the state of historic buildings and identifying surface deterioration, deformation and material anomalies [2,3]. Drone inspection is particularly useful for roofs, towers, cornices, courtyards, high walls and other components where manual access is costly, risky or incomplete. However, the educational challenge is not solved by teaching students how to fly. A graduate who can operate a drone but cannot read a historic building,

design a safe flight plan, judge image quality, interpret visible defects or prepare a professional inspection report is not yet prepared for heritage-oriented inspection work. Vocational undergraduate education provides a suitable institutional position for responding to this challenge. The revised Vocational Education Law of the People's Republic of China emphasises high-quality technical and skilled workers, professional ethics, scientific and cultural literacy and the ability to meet occupational and career-development requirements. Compared with short-term vocational training, a vocational undergraduate programme can combine technical depth, design thinking, project-based practice and professional formation. Compared with a conventional academic architecture programme, it can place greater emphasis on operational procedures, field evidence and workplace adaptability.

This paper addresses one question: how can a vocational undergraduate architectural design programme construct a training pathway for drone-based historic-building inspection under the low-altitude economy? The contribution is conceptual and design-oriented rather than statistical. It synthesises recent literature and policy sources, translates job tasks into a competency framework, and proposes a staged curriculum and assessment model. The purpose is to provide a practical framework that can be adapted by vocational undergraduate institutions with limited but realistic equipment, local heritage resources and school-enterprise collaboration conditions.

For architectural design programmes, this shift is also pedagogically useful because it gives students a concrete reason to connect spatial observation, construction knowledge, digital modelling and professional reporting. In many design courses, digital tools are used mainly for representation after a design idea has already been formed. Drone-based inspection reverses that order: students must first collect evidence from an existing building, then organise and interpret that evidence before producing a professional output. This sequence trains observation and judgement, two abilities that are central to architectural education but are sometimes weakened when teaching relies too heavily on software demonstrations or abstract design tasks.

The issue is especially relevant for private and vocational undergraduate institutions that serve regional

development. Such institutions may not have large laboratories or access to high-end surveying equipment, yet they often have strong ties with local industries and community resources. A pathway built around consumer-level or teaching-level drones, accessible photogrammetry tools and low-risk local heritage sites can therefore be feasible. The key is to design the pathway carefully enough that limited equipment does not lead to shallow learning.

Literature and policy background

Recent reviews show that cultural heritage work increasingly relies on three-dimensional (3D) data, digital models, photogrammetry and multi-source documentation, but also faces problems of standardisation, workflow coherence and data reuse [4]. In the specific domain of heritage-building condition assessment, De Fino et al. reviewed photogrammetric approaches for diagnostic purposes and highlighted their relevance for decay mapping, structural monitoring, multi-source documentation and decision support.

Pepe et al. reviewed the combination of UAV platforms with structure-from-motion and multi-view stereo approaches in cultural heritage, emphasising flight planning, sensor selection, navigation systems, image overlap and 3D model generation. Kong and Hucks further demonstrated how photogrammetry-based digital twins can support monitoring of deteriorations in historic structures. These works suggest that the professional use of drones requires more than flight control [5].

Mishra and Lourenço reviewed artificial intelligence (AI)-assisted visual inspection for cultural heritage and identified defects such as surface cracks, erosion, vegetation, seepage and vandalism as objects of computational recognition [6]. For vocational undergraduate education, AI does not replace foundational field judgement; rather, it increases the need for students to understand how images are produced, labelled, interpreted and reported.

Work-based learning in higher education is widely understood as structured cooperation between educational institutions and industry or workplace contexts, although terminology varies across work-integrated learning, workplace learning and project-based learning [7]. Perusso and Wagenaar argue that work-based learning development in higher education depends on clear learning outcomes, stakeholder

coordination and meaningful workplace tasks [8]. Project-based learning reviews also show that authentic problems, collaborative structures and sustained inquiry support both disciplinary understanding and transferable skills [9].

The policy background strengthens this educational direction. The low-altitude economy has been reported as a fast-growing sector in China, and UAV flight management is moving toward more systematic safety and identification requirements [10]. At the same time, United Nations Educational, Scientific and Cultural Organization (UNESCO)'s Recommendation on Open Science emphasises open educational resources, responsible knowledge sharing and institutional capacity building [11].

A further lesson from literature is the importance of standardisation. Digital heritage projects can produce impressive models but still fail to support conservation decisions if metadata, file naming, coordinate systems, image provenance and reporting formats are inconsistent. This is an educational concern. Students should not be trained to regard a model or a group of aerial photos as their final achievement. They need to learn how inspection evidence is named, stored, explained and connected to a specific building component. This requirement justifies the inclusion of data management and report writing as formal curriculum elements rather than optional after-class tasks.

The literature on project-based learning also cautions that authenticity alone is insufficient. A real-looking task can still be pedagogically weak if roles are unclear, assessment criteria are hidden or students complete only fragmented subtasks. Therefore, the proposed pathway separates project stages and assigns evidence to each stage. This helps teachers monitor participation and makes it possible for students with different strengths to contribute meaningfully while still meeting common learning outcomes.

Research design and analytical framework

This study is designed as a curriculum-development and pathway-construction paper. It does not report a human-subject experiment or claim measured learning gains. Instead, it uses a synthesis logic common in applied education research: policy context and literature define the external demand; job-task analysis translates the

demand into work activities; competency mapping converts work activities into learning outcomes; curriculum and assessment design specify how those outcomes can be taught and evaluated.

The analytical framework contains five steps. First, the occupational scenario is defined as drone-based inspection of historic buildings for documentation, condition recording and preliminary reporting. Second, the job tasks are decomposed into pre-flight preparation, site observation, flight and safety control, image capture, data organisation, defect interpretation, report writing and archive submission. Third, the tasks are grouped into competency domains that can be taught in a vocational undergraduate architecture programme. Fourth, modules and hours are allocated according to the practical weight of each competency. Fifth, assessment evidence is designed so that student performance can be judged through records, products and professional behaviours rather than through a single final examination.

This design deliberately avoids treating drone inspection as a technology course detached from architectural design. The proposed pathway begins with heritage cognition because students must know what they are inspecting and why it matters. It then moves to drone operation, safety and image acquisition, because reliable data depends on field procedure. It continues to process, interpretation and reporting, because inspection evidence becomes meaningful only when converted into a structured conservation-oriented output.

The framework also treats curriculum data as design evidence. In education research, not all numerical information needs to be survey data. Hours, credits, assessment weights and evidence categories are also data when they are used to make the curriculum inspectable and revisable. Presenting these design data in tables and figures allows other teachers to judge whether the allocation is plausible, whether safety receives enough attention and whether practice is sufficiently weighted. This is different from claiming that the pathway has already improved student outcomes.

The boundary of this study is therefore explicit. It proposes a pathway for implementation and evaluation; it does not report a completed intervention. This boundary is necessary for academic integrity. It also makes the paper more useful for institutions that are still preparing similar modules, because it offers a structure

that can be tested, adapted and improved rather than a finished set of universal conclusions.

Competency framework for drone-based historic-building inspection

The competency framework proposed in Table 1 identifies seven domains. The first domain, heritage cognition, requires students to recognise historic-building types, components, material features and conservation value. The second domain, UAS operation, covers aircraft preparation, take-off, landing, hovering and route execution. The third domain, safety and compliance, is treated separately because low-altitude operation involves legal, spatial and public-safety responsibilities. The fourth domain, visual data acquisition, links flight decisions with image quality. The fifth domain, data processing, introduces image sorting; basic orthophoto/model workflow; file naming; archive management. The sixth domain, defect interpretation, connects visual evidence with conservation vocabulary. The seventh domain, communication and ethics, requires students to produce inspection reports, protect sensitive site information and cooperate with stakeholders.

The framework follows vocational undergraduate logic. It does not expect students to become professional conservators, licensed surveyors or AI engineers within one course sequence. Instead, it defines the boundary of a realistic graduate capability: Students should be able to participate in low-risk routine inspection, produce reliable visual records, organise data, identify typical visible problems and communicate findings under teacher or industry supervision.

A key feature of the framework is that each competency

is paired with observable evidence. Flight safety is not assessed by asking students to define safety in writing; it is assessed through a pre-flight checklist, airspace-risk explanation and emergency response procedure. Defect interpretation is assessed through annotated images and a structured inspection sheet. This evidence-based design helps teachers avoid the common problem of practice courses: students appear to participate, but their actual competence remains invisible.

The framework can be translated into progressive learning outcomes. At the introductory level, students should be able to explain inspection objectives, identify major components and complete a supervised safety checklist. At the intermediate level, they should be able to design a simple route, collect complete image coverage and organise data according to a naming rule. At the advanced level, they should be able to prepare a structured inspection report that includes annotated images, preliminary defect descriptions, limitations and recommendations for further professional assessment. This progression helps avoid the common problem of giving students advanced tasks before they have developed basic procedural discipline.

Another advantage of the framework is that it clarifies collaboration between teachers. Architectural teachers can lead heritage cognition, component reading and report logic. Drone-technology teachers or enterprise mentors can lead operations, maintenance and flight safety. Digital-technology teachers can support image processing and model generation. Conservation specialists can advise on defect terminology and ethical boundaries. A competency table therefore becomes not only a student-learning tool but also a division-of-labour tool for the teaching team.

Table 1. Competency framework for drone-based historic-building inspection.

Competency domain	Core indicators	Observable learning evidence	Minimum performance standard
Heritage cognition	Historic-building types, components, material features, conservation value	Annotated component map, short heritage-value note	Identifies major components and explains why inspection evidence matters
UAS operation	Aircraft preparation, take-off/landing, hovering, route execution	Operation log, teacher-observed flight record	Completes basic operation under supervision without unsafe behaviour
Safety and compliance	Airspace awareness, site risk, emergency response, public safety	Flight plan, risk checklist, emergency plan	Explains restrictions and completes safety procedure before flight

Competency domain	Core indicators	Observable learning evidence	Minimum performance standard
Visual data acquisition	Coverage, overlap, view angle, lighting, image sharpness	Image dataset index, sample quality review	Produces complete image coverage for assigned inspection zone
Data processing	Image sorting, basic orthophoto/model workflow, file naming, archive management	Processing screenshots, folder structure, model/orthophoto output	Organises traceable data and produces usable preliminary outputs
Defect interpretation	Crack, seepage, weathering, vegetation, deformation and surface loss recognition	Annotated defect images, inspection sheet	Uses appropriate terminology and avoids unsupported diagnosis
Communication and ethics	Report writing, stakeholder communication, data protection, heritage ethics	Inspection report, reflection memo, archive submission	Communicates evidence clearly and respects site/data sensitivity

Curriculum pathway and project-based implementation

Table 2 presents a 192-hour pathway that can be embedded as a specialised course group, micro-major module or project semester within a vocational undergraduate architectural design programme. Heritage knowledge receives 32 hours so that students can build a basic conservation vocabulary. UAS flight and safety receive 40 hours because operational discipline is essential. Imaging and photogrammetry receive 44 hours because image quality and data processing are the technical core of inspection work. Defect recognition receives 28 hours as a focused bridge between images and conservation meaning. Project practice receives 48 hours to integrate all modules into a complete task.

The pathway should be implemented through staged projects. In the first stage, students analyse a low-risk building or campus architectural element to understand inspection objectives. In the second stage, they complete simulation and ground-based safety drills before operating drones outdoors. In the third stage, they plan routes and capture images under controlled conditions. In the fourth stage, they process images into organised datasets, basic orthophotos or simplified models. In the fifth stage, they annotate visible defects and prepare an inspection report. This staged structure corresponds to the closed-loop model shown in Figure 1.

The role of school-enterprise collaboration is practical rather than decorative. A drone enterprise can support equipment operation, maintenance and safety rules. A

heritage or architectural practice unit can provide inspection cases and report standards. A local cultural institution can provide access to public or low-risk heritage resources. The university coordinates learning outcomes, assessment and student safety.

Project-based implementation also enables differentiated participation. In a real class, not every student will become the lead pilot. Some may specialise in site recording, image organisation, defect annotation, modelling or report writing. This distribution reflects real inspection teams, where safety, data quality and interpretation depend on coordinated roles. The teacher's task is to rotate roles across projects so that students gain both breadth and a clear sense of their strengths.

The 192-hour design can be adjusted to local conditions. If an institution has limited flying space, more early hours can be placed in simulation, ground photography and image interpretation. If it has stable access to a traditional village or historic street, more hours can be assigned to field observation and project reporting. If regulations restrict outdoor drone flights, teachers can still train mission planning, component reading, image dataset management and report writing through pre-collected teaching datasets. The pathway is therefore modular rather than dependent on one ideal site.

A typical project may begin with a conservation question, such as whether the roof edge, wall surface or timber component of a historic building shows visible deterioration that requires further professional inspection. Students then define the inspection boundary, identify possible risks, plan image positions, complete pre-flight checks, collect images, organise the dataset and prepare

a report. The teacher should require students to explain what their data can and cannot show. This limitation statement is important because responsible inspection does not turn preliminary visual evidence into an unsupported diagnosis.

The pathway can also support entrepreneurship and local service learning. Students who master the workflow may later work in architectural documentation, cultural

tourism, village renewal, digital archives, urban inspection or drone-service companies. However, the programme should avoid presenting these opportunities as guaranteed employment outcomes. The immediate educational aim is more modest and more defensible: to cultivate students who can join interdisciplinary teams with a clear understanding of inspection tasks, data quality and professional responsibility.

Table 2. Proposed modular curriculum and project evidence.

Module	Key content	Hours	Credits	Project evidence
Historic knowledge	Building types, components, materials, conservation principles	32	2.00	Component map, case-analysis note
UAS flight and safety	Drone structure, flight control, route planning, risk management	40	2.50	Flight plan, safety checklist, operation log
Imaging and photogrammetry	Image overlap, oblique capture, dataset management, basic SfM-MVS workflow	44	2.75	Image dataset, processing screenshots, model sample
Defect recognition	Visible defects, annotation rules, inspection terminology and reporting boundaries	28	1.75	Annotated images, defect classification sheet
Project practice	Simulated or low-risk field inspection, group roles, report preparation and presentation	48	3.00	Complete inspection portfolio and presentation
Total	Five-module specialised training pathway	192	12.00	Evidence portfolio

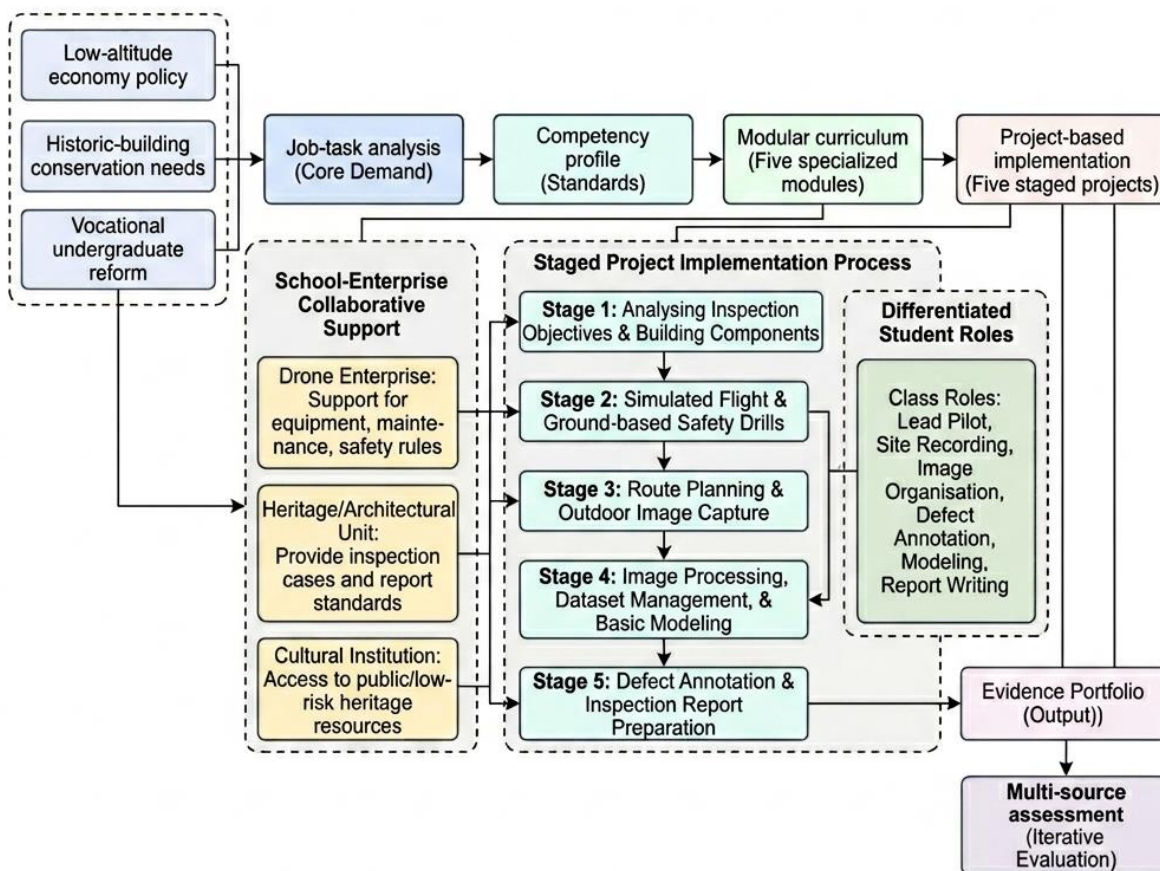


Figure 1. Closed-loop training pathway for vocational undergraduate drone-inspection talent.

Assessment, quality assurance and evidence portfolio

Assessment is the hinge between curriculum design and actual competence. If assessment remains limited to a written test or final report, the programme cannot judge whether students can operate safely, acquire usable data or work responsibly on a heritage site. Table 3 therefore proposes a 100-point assessment system divided into six evidence categories: heritage-task diagnosis, flight planning and safety, image acquisition quality, data processing output, defect interpretation and reporting, and reflection and professional ethics.

The assessment system has three principles. First, safety is non-negotiable. A student who cannot complete basic safety procedures should not pass the practical component, even if the final report looks polished. Second, data quality must be evaluated before interpretation. Poor images, missing coverage or disorganised files weaken every later claim. Third, professional communication should be judged through report structure, terminology, visual annotation and evidence traceability.

An evidence portfolio can make assessment transparent. The portfolio should include the flight plan, safety checklist, field photos, image dataset index, processing screenshots, annotated defect images, inspection report and reflection memo. Teachers, enterprise mentors and peer reviewers can each evaluate selected components. Figure 2 summarises the curriculum-hour distribution and assessment-weight allocation. The data in the figure are design data for curriculum planning, not empirical outcome data.

Quality assurance should be cyclical. After each project, teachers should review which tasks caused the most

errors: unclear route planning, weak camera settings, incomplete coverage, poor file naming, inaccurate defect terminology or superficial reflection. These problems should feed into the next iteration of teaching materials.

The portfolio approach also supports formative feedback. A teacher can comment on a route plan before a flight, on image quality before processing, and on annotation accuracy before the final report. This staged feedback is more effective than correcting a completed report at the end of the project, because many errors in drone inspection are cumulative. A poorly defined inspection target leads to a poor route; a poor route leads to incomplete images; incomplete images lead to weak interpretation. Assessment should therefore interrupt errors early rather than merely record them at the end.

Multi-source assessment is valuable, but it must be organised carefully. Enterprise mentors should not simply give a general impression score. They can evaluate operational discipline, equipment handling and workplace communication. Course teachers can evaluate learning outcomes, report structure and theoretical understanding. Peers can evaluate collaboration and role fulfilment. External reviewers from heritage or architectural practice can judge whether the final report is understandable and professionally cautious. Each evaluator should assess the part of the evidence that matches their expertise.

Quality assurance also requires attention to safety incidents and near misses. Even if no accident occurs, records of unstable hovering, weak communication, incomplete site control or missed weather checks should be treated as learning evidence. A safe training pathway is not one in which risks are hidden; it is one in which risks are anticipated, documented and used to improve procedure.

Table 3. Assessment evidence and weight allocation.

Assessment component	Weight	Primary evidence	Evaluator
Heritage-task diagnosis	15%	Site reading note; inspection objective statement	Course teacher
Flight planning and safety	25%	Route plan; checklist; emergency procedure; operation log	Teacher + enterprise mentor
Image acquisition quality	20%	Coverage rate; sharpness; overlap; dataset index	Teacher + peer review
Data processing output	20%	Organised folder, processing screenshots, orthophoto/model sample	Course teacher
Defect interpretation and reporting	20%	Annotated images, inspection sheet, final report	Teacher + external reviewer
Reflection and professional ethics	Embedded	Reflection memo; data-protection compliance	Teacher

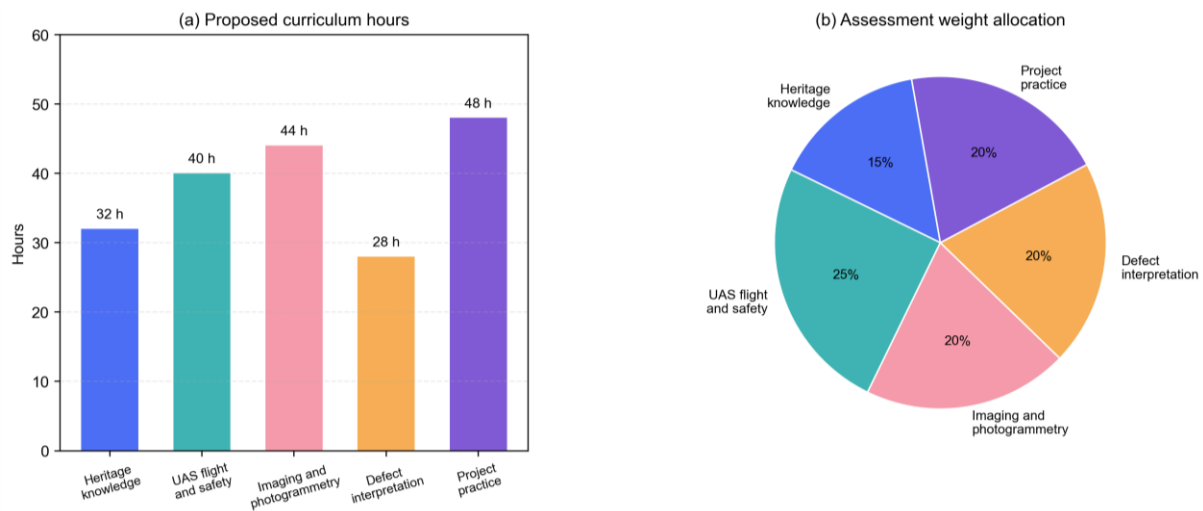


Figure 2. (a) Curriculum-hour distribution, (b) assessment-weight design data.

Discussion

The proposed pathway has three implications for vocational undergraduate architectural design education. First, it reframes drone training as scenario-specific professional education. A drone course that focuses only on flying may improve operational confidence, but it does not automatically produce heritage-inspection competence. The value of the pathway lies in combining architectural knowledge, field procedure, image-based evidence and report writing.

Second, the model supports a realistic form of interdisciplinary education. Interdisciplinarity is often described in broad terms, but students need an operational sequence. In this pathway, interdisciplinarity appears through tasks: A student reads a roof structure, designs a route, captures oblique images, processes data, annotates a defect and explains the finding in a report. The sequence makes the integration of architecture, UAV technology and digital documentation visible.

Third, the pathway can serve local development. Many vocational undergraduate institutions have limited access to nationally protected heritage sites, but they may have access to campus buildings, historic streets, traditional villages or publicly accessible cultural landscapes. These resources can support low-risk training while also helping students understand regional culture.

The model also has limitations. It is a design proposal rather than a completed intervention study. It does not yet provide pre-test and post-test data, employer satisfaction evidence or graduate tracking. Equipment, weather, airspace approval and site access may affect

implementation. Future research should conduct a semester-long pilot, collect portfolio evidence, compare student performance across project stages and interview teachers, enterprise mentors and site managers.

The pathway also responds to a broader tension in vocational undergraduate education: How to balance undergraduate-level thinking with vocational-level practice? If a programme focuses only on theory, it may lose its occupational relevance. If it focuses only on operation, it may become short-cycle training. Drone-based historic-building inspection offers a productive middle ground because students must understand a meaningful object, follow a technical procedure, produce evidence and justify decisions. This combination can help vocational undergraduate education demonstrate its distinctive value.

For international readers, the case also shows how low-altitude economy policy can be translated into curriculum design. Policy terms often remain abstract in education papers. The proposed model converts the policy term into tasks, competencies, hours, evidence and assessment. This translation is important because educational reform becomes credible only when broad policy language is connected to classroom and field procedures.

There is also a cultural dimension. Historic-building inspection is not only a technical service. It trains students to observe inherited environments with care. When students document a roof tile, a wall crack or a timber joint, they learn that digital technology should serve cultural understanding rather than replace it. This value orientation is essential if low-altitude technology

is to support heritage protection rather than turn heritage sites into ordinary visual-data objects.

Conclusion

The low-altitude economy creates new opportunities for vocational undergraduate education, but these opportunities become educationally meaningful only when they are translated into specific occupational scenarios. Drone-based inspection of historic buildings is a promising scenario for architectural design programmes because it connects heritage cognition, flight safety, digital imaging, data processing and professional reporting. This paper proposed a closed-loop training pathway that begins with job-task analysis, builds a competency profile, reconstructs modular curriculum, implements staged projects and evaluates learning through evidence portfolios. The framework is bounded: it does not claim to produce expert conservators or advanced AI engineers. It aims to prepare vocational undergraduate students to participate responsibly in routine, low-risk and supervised historic-building inspection work. With further pilot testing and local adaptation, the pathway can help vocational undergraduate institutions align architectural education with low-altitude economy development and cultural heritage protection.

The next practical step is a controlled teaching pilot. Such a pilot should record the number of students, project duration, equipment type, site conditions, task completion records, portfolio quality and feedback from teachers and external mentors. A pre-course and post-course competency self-assessment may be used, but it should be combined with product evidence and observed behaviour. Only after such data is collected can the pathway be evaluated as an empirical teaching reform. Until then, the contribution of this paper is to provide a coherent, citable and implementable design framework.

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Conflicts of Interest

The author declares no conflict of interest.

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