CONSTRUCTION INNOVATION HUB

INDUSTRIAL STRATEGY | UK Research and Innovation

Introduction to

Construction Quality Planning

Applying APQP to construction manufacturing

Construction Innovation Hub

The Construction Innovation Hub brings together world-class expertise from the Manufacturing Technology Centre (MTC), BRE (Building Research Establishment) and the Centre for Digital Built Britain (CDBB) to transform the UK construction industry.

With £72 million from UK Research and Innovation's Industrial Strategy Challenge Fund, we will change the way buildings and infrastructure are designed, manufactured, integrated and connected within our built environment.

We will be a catalyst for change. We will drive collaboration to develop, commercialise and promote digital and manufacturing technologies for the construction sector. We will help build smarter, greener and more efficient buildings much faster and cheaper than we currently do.

Research will help us understand how the industry must change in terms of skills, product standards, capacity and innovation. This will be combined with an academic programme to create the security-minded frameworks and rules that will underpin the future digital built environment and grow exports for UK know-how.

We will work closely with other initiatives as part of the Government's Transforming Construction challenge programme. Through collaboration across the sector, we can provide a better built environment for future generations.

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Construction Quality Planning for Manufacturing-led Construction

The construction industry is on the verge of an industrial revolution. This revolution will usher in the mainstream use of new and innovative materials and processes; tools that will enable the industry to be more productive while meeting the growing demand for buildings, housing and infrastructure in the United Kingdom.

As more and more construction processes move offsite, new partners will be attracted into the supply chain and new quality standards will be required. Understanding some of the quality methodologies and terminology already in use in the manufacturing sector will be beneficial for existing construction suppliers.

Construction Quality Planning (CQP) is a quality tool under development by the Construction Innovation Hub. It is an adaptation of Advanced Product Quality Planning (APQP), which is already in broad use throughout the manufacturing industry, and will be aimed at those enterprises that will feed construction with componentry for offsite builds. Using CQP will ensure that parts conform to the fit, form, and function needed by the industry as well as uphold the quality standards that construction will require as they fully engage with the coming industrial revolution. The CQP methods and underlying toolsets will provide a standardised process with measurable quality data and outputs. This could help pave the way for future accreditation schemes, providing confidence to clients, insurers, lenders, and contractors. The feedback and problem-solving mechanisms within CQP would bring the industry together in identifying corrective and preventative actions and documenting lessons learnt.

Background

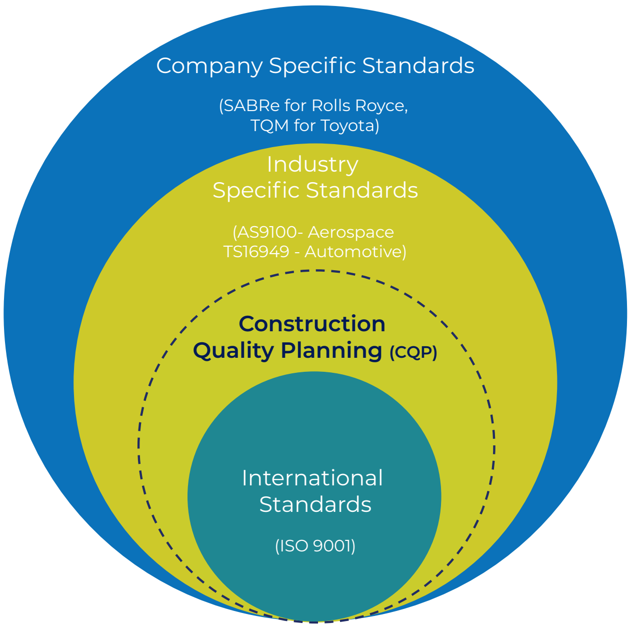
APQP is a methodology for ensuring that quality is factored into the entire product development cycle, from concept design through to the full-scale implementation of a manufacturing strategy[1] [2]. It is employed throughout the manufacturing sector on a global scale to effectively 'build in' the customer quality requirements. Several key questions arise at this stage: Who is the customer, what does the customer want, how do we deliver to the ever-changing needs and expectations of our customers.

In order to answer some of these questions, specific toolsets can be applied in the APQP methodology. APQP uses quality assurance processes and applies continuous improvement ideologies at every phase to enable the delivery of a defect-free product achieving customer requirements at the expected demand rate.

It has been recently identified that some key areas for improvements in offsite construction are design, standardisation for interfaces, connections, accuracies and tolerances, as well as documenting lessons learnt[3].

Many of the tools included within APQP can be adapted to construction, providing improved quality and therefore address the identified bottlenecks for the sector. In sectors such as aerospace and automotive, industry specific standards provide guidance on applying these tools. We are calling this industry specific guideline for construction CQP, its position within existing quality standards is shown in **Figure 1.**

Figure 1: Tiered quality management approach



[1] Automotive Industry Action Group, Advanced product quality planning (APQP) and control plan reference manual, second edition, Southfield, MI: AIAG, 2008.

[2] Aerospace Series – Requirements for advanced product quality planning and production part approval process," Society of Automotive Engineers, AS9145, 2016.

[3] C. I. Goodier, F. Fouchal, C. Price and N. Frasier, "The role of standards in offsite construction. A review of existing practice and future need.," BSI, London, UK, 2019.

An Overview of Construction Quality Planning

This introductory guide is aimed at providing an overview of the CQP process that the Construction Innovation Hub team is currently developing. The overall process framework is depicted in **Figure 2**.

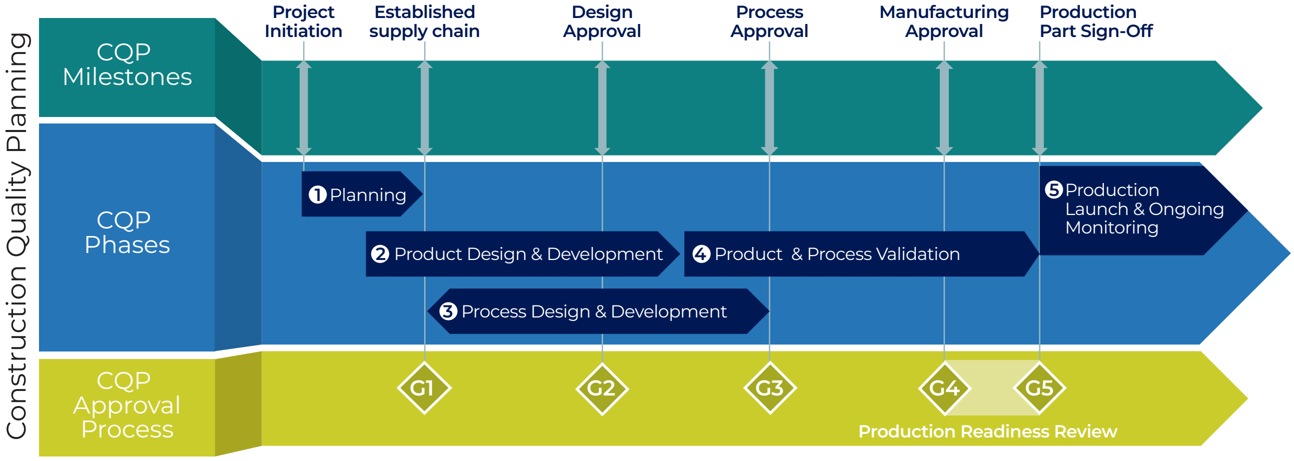
This overview is broken down into three main elements of CQP:

1. The Five Phases.

2. CQP Toolbox.

3. The Gated Approval Process.

Figure 2: Construction Quality Planning framework



The Five Phases of Construction Quality Planning

CQP is split into five phases (shown in **Figure 3**) which develop the product from the initial design requirements through to full production and supply. The use of the phased approach is based on Simultaneous Engineering principles. Tasks traditionally carried out in sequence by separate teams with results being passed on are now carried out simultaneously by cross-functional teams - all through the CQP process. When outputs are known from tasks in one phase, they can be inputted into the activity of the next phase rather than waiting for the phase to complete. The phases therefore overlap, are iterative, and are carried out simultaneously with the team working across the whole project rather than on individual specialisms or parts of the project timeline.

Phase 1. Planning.

This phase refers to building the Voice of Customer into easy-to-interpret requirements and using the Voice of the Organisation to establish deliverables and a Quality Functional Deployment (QFD). A key task in the planning phase is also to understand and capture any relevant regulations that go along with the customer requirements. Organisations might also set their high-level Key Performance Indicators (KPIs) and targets during this phase.

Phase 2. Product Design and Development.

The aim of this phase is to ensure that the product, as designed, is verified and validated against the requirements laid out in planning. Design validation at this phase typically takes the form of mature prototype testing (not necessarily following a fully productionised process), to verify that it meets or exceeds the customer requirements.

Phase 3. Process Design and Development.

This is a key step in the manufacturing supply chain and runs concurrent with both product design and overall validation. The aim of this phase is to establish a manufacturing process that can consistently produce conforming product at the customer demand rate.

Figure 3: The five phases of CQP.

Phase 4. Product and Process Validation.

The aim of this phase is to validate the product quality and manufacturing process at a productionised demand rate. The key differentiator being that product quality must be met in a full production environment. In the construction industry, phase 4 will provide a clear path for all production validation activities.

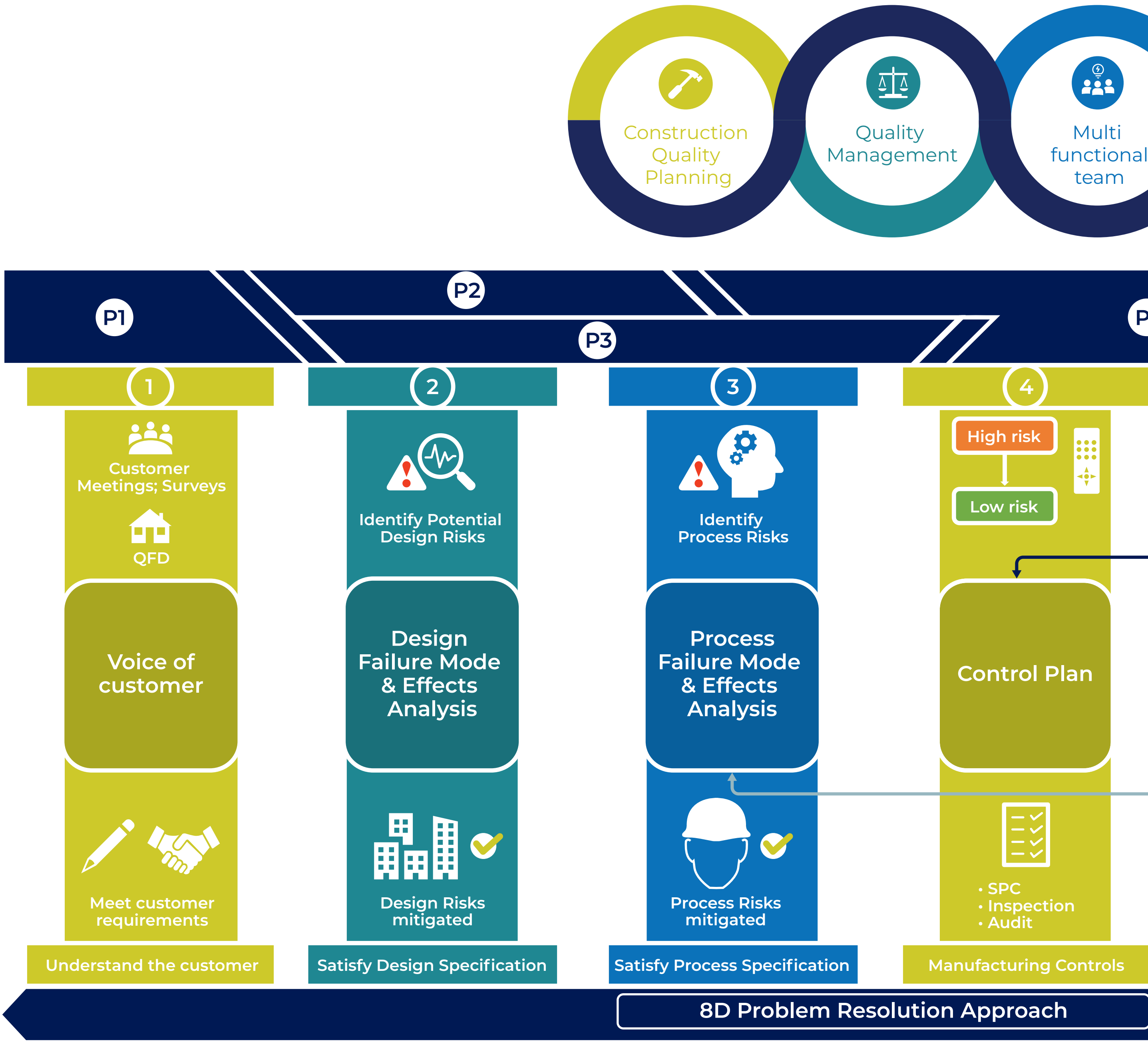
Phase 5. Production Launch and On-Going Monitoring.

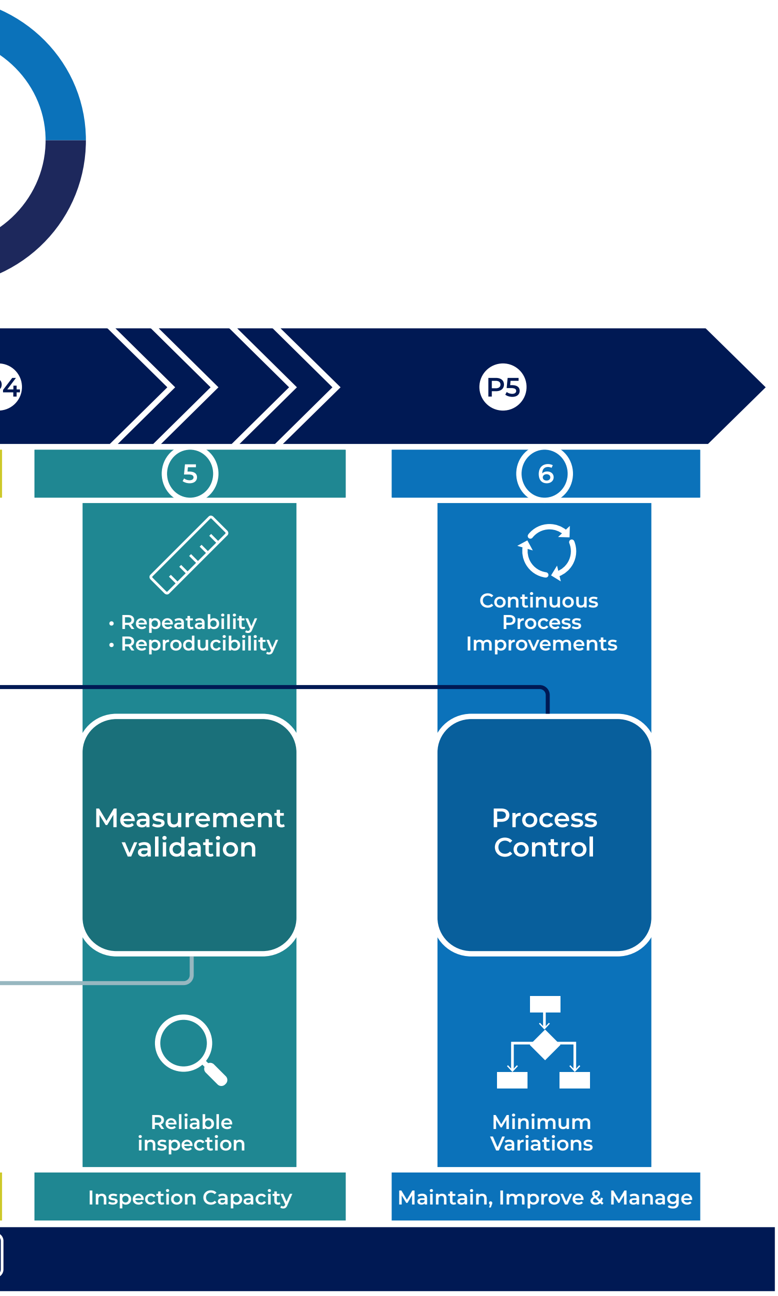
This phase ensures that when the volume of offsite production ramps up, the validated production process achieves the desired performance targets as determined at the start of the CQP process. The product can then be fully approved and handed over to the production team. This initiates the full production process where the process needs to remain in a state of statistical control. This is an ongoing process of monitoring the quality of the product in production against the criteria agreed with the customer. This phase can be further adapted to the construction industry by monitoring specific elements of whole-life performance and sustainability checkpoints such as: material consumption, embodied carbon and energy use. Therefore, construction products can be monitored over their entire production life in order to meet the performance targets set out for the industry. During this phase, the CQP team and production teams will also complete a lessons learnt document to feed back into future applications for new product introduction. As part of ongoing production monitoring, the production team will carry out continuous improvement activities.

CQP Toolsets in Construction

The main toolsets applied during CQP are summarised below; their application through the phases (P1-P5) is outlined in **Figure 4**.

Figure 4: CQP Toolbox to drive zero defects





Quality Functional Deployment: QFD is a structured approach to defining the customer needs and translating them into specific product development plans. Often referred to as a 'house of quality', this tool builds the Voice of the Customer and the Voice of the Organisation into the development process to ensure a technically feasible solution that meets those needs. Various methodologies such as market research, surveys, and the Analytic Hierarchy Process[4] are used to determine the customer priorities. This is fed into the 'house of quality' in the order of importance with individual weights assigned to each requirement based on survey results. After establishing 'what the customer wants', the next step is to fill the QFD with 'how do we deliver this'. While completing the 'house of quality', interdependencies between all the 'whats' and 'hows' are determined through a team-based approach. The QFD then looks at the customer priorities, interdependencies of requirements (whats) and organisation's capabilities (hows) in order to compute weightings for the different solutions which can be delivered by the organisation. This process is repeated iteratively until a final decision has been reached through consensus within the CQP team. QFD is useful for team-based decision making and documenting the overall concept/ design stage in an easy to understand visual representation. In the construction sector, requirements capture can be streamlined through the application of such methodologies.

[4] T. L. Saaty, "Decision making - the analytic hierarchy and network processes (AHP/ANP).," Journal of systems science and systems engineering, vol. 13, 2004.

Failure Mode and Effects Analysis (FMEA): FMEA is a widely used toolset within the manufacturing sector. The FMEA tools are used to carry out design and process risk analysis. FMEA looks at potential failures, the probability of failure occurring and the effect of these failures. It ranks these risks in terms of severity, occurrence and detection. The CQP team can then identify and take the appropriate actions.

Design Failure Mode and Effects Analysis (DFMEA) is used during the product development phase (as shown in Figure 4, pillar 2). Any design features identified as having the possibility of causing major, hazardous or catastrophic failures are either removed from the product or have prevention mechanisms built in to reduce their failure rate. Key outputs from DFMEA are feature classifications for the product and identification of Key Characteristics (KCs). In the construction sector, such key characteristics may comprise of interfacing features between modules, cladding, substructures and foundations. Critical Items (CIs) may be on products which are critical to the structural integrity of the buildings for example beams or columns.

Process Failure Mode and Effects Analysis (PFMEA) is applied in Phase 3 of CQP (see Figure 4, pillar 3) to analyse risks to the product through the failure of the process at the different manufacturing steps. The risks analysed at this stage are not only for the customer but also for the manufacturer. In order to complete the PFMEA, a preliminary manufacturing process flow must be established and the DFMEA must be complete. The key outputs from the PFMEA are identification of the process key characteristics and the control plan.

Control Plans and Reaction Plans: For high risks identified within the PFMEA, a control plan is created. Just like the DFMEA and PFMEA, the control plan is product specific and should not be confused with a maintenance or asset care plan. The control plan provides for monitoring of high-risk features, product and process KC through established error-proofing techniques or advanced inspection methods. In situations where a control method might fail, a reaction plan is also required. A good practice on a manufacturing shop floor is to have some key reaction plans in the form of laminated, numbered documents (for example: reaction plan 1, reaction plan 2 and so on) which can be quickly implemented when required.

Measurement System Analysis (MSA): Measurement System Analysis is a tool that is used to validate measurement systems. This can include subjective measuring equipment such as templates used while checking that the wall colours are to customer specifications; to automated sensor equipment that provide measured values for indoor air quality. MSA looks not only at the equipment being used but also human factors, environment, location and the inspection process. A complete MSA study can provide confidence, to all parties involved in the construction process, that the data has been validated through a comprehensive process.

Process Control (PC): PC enables monitoring of the process in such a way that any variation showing instability in the process can be quickly identified and acted upon. In the manufacturing sector, this is referred to as 'special cause variation'. By getting rid of such 'special cause variation' the process becomes stable and quality becomes predictable. More advanced process controls can be established as the manufacturing process becomes more mature. Process capability indices are sometimes used to monitor the KCs or CIs identified by the DFMEA. These indices provide for monitoring the short-term and long-term capability of a given process. Therefore, clients and tier 1 contractors can be assured that the supply chain have achieved minimum acceptable maturity through the adoption of this toolset.

Eight Disciplines of Problem Solving (8D): This problem-solving methodology is often used in the manufacturing sector and is referred to as '8 Disciplines of Problem Solving'. The 8D method has been developed to identify the root cause for any non-conformances found in the product. Such a situation arises when the internal or external customer receives a product and later identifies that the product has issues with its 'fit, form or function'. The 8D method can then be used to contain the stock, define the problem, identify and verify the root cause(s) of the non-conformance and put in place corrective as well as preventative measures. This is fed back into the FMEA tools and the Control Plans ensuring ongoing continuous improvement.

CQP Gated Approval process

Whilst the five CQP phases may run simultaneously, each phase has a primary focus and needs to be completed with its set of activities. At the end of each phase, there is a Gate which acts as a sign off for the phase. In order for a gate criterion to be successfully achieved, certain activities need to have been completed against set targets pre-agreed with the customer representative. The Gate can be signed off both internally and by the customer. Any failures observed during the approval process require corrective and preventative actions to be put in place before proceeding further. The gates therefore build up to make the CQP approval process ensuring quality is being built in, the results are being monitored and targets achieved at all stages of the process. The gated approval process is described in **Table 1** and its associated **Figure 5**.

Figure 5: CQP Gated Approval Process.

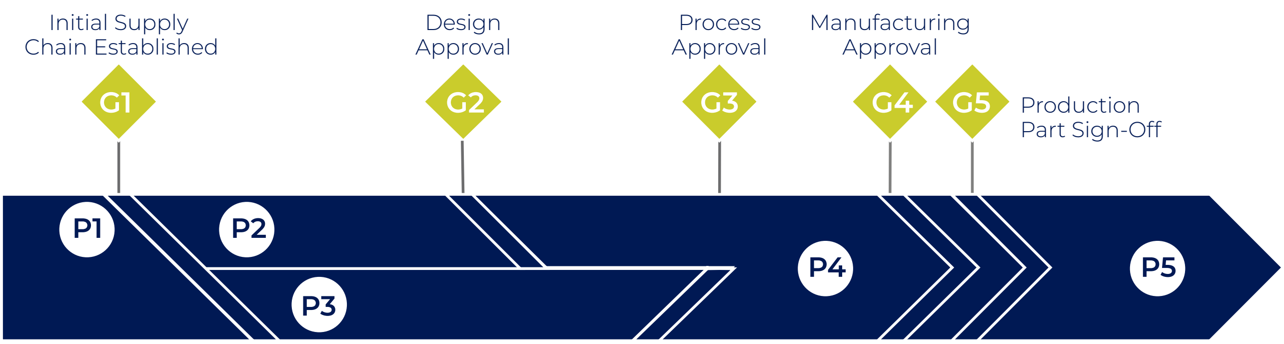


Table 1: CQP Gated Approval Process.

Approval Gates	Gate Criteria		
	Sign off	Kick off	Update
G1. Initial Supply Chain Established	Project Plan, Product Design Specification (PDS), Preliminary Sourcing Plan	Bill of Materials (BOM), Preliminary Process Flow, CIs	
G2. Design Approval	BOM, DFMEA, DFMA Design Verification (DVP&R), Packaging System	Design Change Records, Production Readiness Review, KCs	Project Plan, Process Flow Chart, CIs
G3. Process Approval	Process Flow Chart, CIs and KCs, PFMEA, Material Handling and Labelling, Production Readiness Review, Process Instructions	Control Plan MSA Capacity Verification	Project Plan
G4. Manufacturing Approval	Control Plan, MSA, Quality & Capacity Report, Product from production process run, Production Validation Testing, Customer Specific Requirements	First-off Product to Site Buy Off	Project Plan
G5. Production Part Sign-Off	First off Product to Site Buy Off.		Project Plan

Next steps

The Construction Innovation Hub is currently liaising with industry partners to develop proof-of-concept case studies to demonstrate applicability and value of these toolsets for the sector.

The next step will be publication of comprehensive guidelines for use of the toolsets and associated documentation to help the construction sector during new product introduction. Publication is due Winter 2019/20.

List of Abbreviations and references

8D	Eight (8) Disciplines of Problem Solving
APQP	Advanced Product Quality Planning
BRE	Building Research Establishment
BOM	Bill of Materials
CI	Critical Item
CQP	Construction Quality Planning
DFMEA	Design Failure Mode and Effects Analysis
DVP&R	Design Verification Plan and Report
FMEA	Failure Mode and Effects Analysis
KC	Key Characteristic
KPI	Key Performance Indicator
MSA	Measurement Systems Analysis
MTC	The Manufacturing Technology Centre
PDS	Product Design Specification
PC	Process Control
PFMEA	Process Failure Mode and Effects Analysis
QFD	Quality Functional Deployment

References and Recommended Reading

[1] Automotive Industry Action Group, Advanced product quality planning (APQP) and control plan reference manual, second edition, Southfield, MI: AIAG, 2008.

[2] Aerospace Series – Requirements for advanced product quality planning and production part approval process," Society of Automotive Engineers, AS9145, 2016.

[3] C. I. Goodier, F. Fouchal, C. Price and N. Frasier, "The role of standards in offsite construction. A review of existing practice and future need.," BSI, London, UK, 2019.

[4] T. L. Saaty, "Decision making - the analytic hierarchy and network processes (AHP/ANP).," Journal of systems science and systems engineering, vol. 13, 2004.