Quality Management for the Built Environment

Gabriella La Rocca

Abstract The quality management chapter begins with defining quality. It explains that quality is not what most think and attempts to eliminate assumptions such as: quality is a luxury and only accessible to large organisations that can afford to employ quality managers. It is in fact the result of a carefully constructed cultural environment. It also demonstrates that just having a quality management system in an organisation does not guarantee quality. The importance of having quality in the organisation's DNA, regardless of size and turnover, is shown. It demonstrates who manages quality, how to manage it, why it is important, when does quality begin, and the cost of poor quality. It lays out the dangers of not managing and understanding it. It explains the importance of having a quality management system in construction companies: how planning, control, and improvement are implemented. Continuous improvement is demonstrated. With case studies, the consequences of not managing quality are shown. Readers are provided with essential information on what they can do to manage quality.

Keywords Quality · Prevention · Continuous Improvement · Non-conformance · Requirements

1 Introduction

The quality management chapter begins with defining quality. It explains that quality is not what most think and attempts to eliminate assumptions such as: quality is a luxury and only accessible to large organisations that can afford to employ quality managers. It is in fact the result of a carefully constructed cultural environment. It also demonstrates that just having a quality management system in an organisation does not guarantee quality. The importance of having quality in the organisation's DNA, regardless of size and turnover, is shown. It demonstrates who

G. La Rocca (✉)
University of Strathclyde, 16 Richmond St, Glasgow G1 1XQ, UK
e-mail: gabriella.larocca@macegroup.com

M. Bolpagni et al. (eds.), *Industry 4.0 for the Built Environment*,
Structural Integrity 20, https://doi.org/10.1007/978-3-030-82430-3_15

manages quality, how to manage it, why it is important, when does quality begin, and the cost of poor quality. It lays out the dangers of not managing and understanding it. It explains the importance of having a quality management system in construction companies: how planning, control, and improvement activities are implemented. Continuous improvement is demonstrated. With case studies, the consequences of not managing quality are shown. Readers are provided with essential information on what they can do to manage quality. This chapter demonstrates that while Industry 4.0 for some is understood as a technical revolution, it is changing how an excellent product/service or experience is delivered. However, the systems and tools to manage quality are not aligned to the latest Industry 4.0 developments. As construction organisations in the UK are focussed on delivering a quality assured building Industry 4.0 provides an opportunity to re-establish a quality culture the industry urgently needs. Although quality management became popular in the 80's and 90's, twenty-first century enterprises in the era of Industry 4.0 are still struggling with the concept as this chapter demonstrates. An excellent quality environment is required through a robust culture where every employee should have a passion to imbue rather than simply follow quality control tools or imitation of best procedures and practices. Creating passion through leadership emphasis, message credibility, peer involvement, employee ownership, and autonomy may substantially reduce and eliminate the cost of poor quality.

2 Quality

Technology is revolutionising how quality is managed. Industry 4.0 has propelled quality management, traditionally perceived as a standalone discipline, into becoming a core practice embedded into the organisation's culture. Despite the innovation introduced with digitisation, quality is mismanaged. According to the UK's Get It Right Initiative (GIRI), poor quality is costing the construction industry in the UK over £20b a year. GIRI is reported that only 13% of construction organisations have quality into everything they do from employing the right people to producing products /services that customers want [1].

As the construction industry grapples with a new industrial reality there is increased pressure on organisations to produce and deliver excellent products/services on time and in budget. Manufacturing industries must operate in a highly sophisticated global environment, the pressure to satisfy customers and retain their market position is continuously increasing. The key to success and an indispensable requirement to gain global market share is to focus on quality management [2].

Sections 2, 3, and 4 of this chapter demonstrate the importance of quality and describe how quality should be managed if an organisation intends to survive in an increasingly competitive market. Despite the new challenges, the fourth industrial revolution has created an opportunity for the cultural change the construction industry needs. Section 8 explains that quality is not about good or bad process, it is about creating the right environment that allows its people to deliver excellent customer service.

Many find quality hard to define. They have their own understanding of quality based on their own experiences. When asked to define quality, they describe it as a product or service of good or bad quality, making a subjective evaluation. When they refer to quality people, for example, they mean those of high social standing. There is an assumption that quality means excellent standard, indicating a distinctive and desirable attribute or characteristic. The term quality is not explained. Quality is simply defined as "conformance to requirements" [3].

In construction project management textbooks, quality is explained as an assessment that determines if a product or service is fit for purpose; "fit for purpose" means that a set of criteria and requirements has been met. When the criteria of a product or service have been defined and requirements established, quality becomes tangible and can be quantified and measured. The conformance to those requirements determines the quality of a product or service. Good quality is conformance, non-conformance is bad quality. A requirement is a need, expectation, or obligation. Requirements need to be clearly defined, understood, and communicated to all key stakeholders before solutions of how the products or services are delivered to clients. Failing to do so causes scope creep, disagreements during the handover of a project, client dissatisfaction, low project team morale as they spent time and effort building what the client did not want [4]. Requirements are set at the bid stage and when a project has been awarded, the requirements are confirmed. They become *contractual*. They are recorded, monitored, and revised throughout the project life cycle. Project failure is certain if requirements are not managed. The goal is to meet requirements on time, first time, and every time. Digitisation has given a new opportunity to control how services and products are delivered and compare them against the initial requirements.

In the construction industry, quality is providing a building or infrastructure that is fit for purpose and is safe for the end user. Every project operates in a legal and regulatory environment which influences the quality planning. These mandatory requirements include acts, international standards, directives, regulations, and organisational governance. In addition to these, there are the clients' requirements which consist of, but not limited to, building purpose, design specifications and the overall look and feel of a building or infrastructure.

3 Quality Management

Managing quality is about prevention, risk, control, record keeping, reporting on performance, improving decision making, and providing assurance that service and products are delivered to the requirements and standards established. Organisations require assurance that quality controls, record keeping and reporting are managed to the standard they have set. Assurance is part of quality management, however, most use it to refer it to quality and think that quality and assurance are the same. Assurance is providing confidence to key internal and external stakeholders that the service or product is compliant to the requirements and that risk is controlled [5].

Assurance is part of quality management. Assurance is embedded in all the tasks of the quality management system.

3.1 Prevention

Planning, controlling and improvement tasks make prevention possible. As prevention costs slowly rise the failure costs fall dramatically [6]. The purpose of managing quality is to prevent non-conformance from happening in the organisation's performance cycle, to monitor risk, and to continuously improve products and services by analysing corrective actions and eliminating the root cause. With the use of different technologies and approaches presented in this book (such as virtual reality and building information modelling), it is possible to prevent errors from happening later in the process.

3.2 Risk

A key aspect of managing quality is monitoring risk. Specialists in risk management have concerns that with digital solutions and automated reporting the more data an organisation has available, the more the uncertainty and the inaccuracy. Interpretation of data is subjective. Verification and validation processes of empirical data available to the organisation are required in the quality management system as explained in chapter "Building Information Modelling and Information Management". The ISO 19,650–2 states that a risk register containing the risks associated with the timely delivery of information shall be introduced [7].

3.3 Control

A quality management system (QMS) provides construction project managers and their team a framework to deliver a product or service in a controlled and predetermined way. Control in this context is not to be confused with the quality control techniques described in Sect. 4. A QMS is a set of interrelated or interacting elements of an organisation to achieve the quality objectives. The purpose of the QMS is to monitor and provide evidence that quality requirements and regulatory, statutory requirements are met. It provides clarity on roles and responsibilities for doing what, when, how, why, and where. It captures key inputs and outputs at each stage, known as gateway, of a project. The gateway process looks ahead to provide control and assurance that the project can progress successfully to the next stage. The Association of Project Management's gateways process consists of: concept, definition, launch, delivery, handover/commissioning. Construction projects have

additional gateways. In the UK's Government funded programmes, it is likely that management systems will be based upon the Office of Government Commerce (OCG). Gateways process which is sponsored by the UK Cabinet Office through the Major Projects Authority. Other typical gateway processes include: The Royal Institute of British Architects RIBA Plan of Work, Network Rail's Guide to Railway Investment Process (GRIP), and the PRINCE2 lifecycle. An online QMS contains policies, standards, templates, and procedures required to meet compliance standards at each gateway and enables real-time progress of each gateway. One of the workstreams of the gateways is digital pathway which lists tasks to manage the digital data during the project lifecycle. They include: establishing information requirements, defining the digital strategy including information management strategy and IT strategy, appointing a BIM Lead to undertake the information management function, establishing the projects' information production methods and procedures, establishing the common data environment, establishing exchange information requirements, producing a BIM execution plan, establishing the information delivery plan, setting up the digital system(s), ensuring the project functions align to the BIM ISO 19,650–2:2018, capturing lessons learned for future projects. The gateway process map should be integrated in the common data environment (CDE) workflows and solutions to facilitate the control of the process.

3.4 Record Keeping

Documentation is defined as the information created for an organisation to operate. A record is defined as the evidence of the results achieved [5].

Maintaining documents is essential. Upon award, the construction project management company confirms the document control strategy with the client. Evidence is required throughout the project lifecycle to demonstrate that the established requirements are being delivered. At handover, the client is provided with the building's maintenance documents. The benefits of good record keeping are to demonstrate that quality is managed and that change (project, design, regulatory) is controlled and communicated. The common data environment (CDE) is the single source of information used to collect, manage and disseminate documentation, the graphical model, and non-graphical data for the whole project team (all project information whether created in a BIM environment or in a conventional data format). Creating this single source of information facilitates collaboration between project teams and helps avoid duplication and mistakes. Ownership of information within the CDE remains with the originator of that information. The planning, the controls, the performance, and improvement activities outlined in the quality plan are not valid if there are no records to demonstrate that they have taken place.

The importance of good record keeping is underestimated. Arcadis, one of the UK's largest design and consultancy organisations, reported that the UK construction industry spends US $34 million on disputes, higher than in other European

countries and the US [8]. Disputes are stuck at the resolution stage with parties not agreeing on the work that was carried out as there are no records to prove the work was completed.

One of the key findings of the report by Dame Judith Hackitt on the Grenfell Tower tragedy in 2017 entitled "Building A Better Future" was poor record keeping [9]. Tracing the materials used for building was non-existent. Hackitt [9] confirmed that "It is not enough to say what you intend to build you must demonstrate what has been built on evidence and proof". "How can you manage the safety of a building when it is occupied for the next 50–60 years if we can't find the records of where and what we started with in the design and construction?" Hackitt [9]. Clause 7.5.2 in the ISO 9001, **"**Creating and Updating", details the requirements of a robust document control strategy. Clause 7.5.3 "Control of documented information", requires distribution, access, retrieval, use storage, preservation legibility, version control, retention, and disposition of all records [10]. In general, A QMS has three layers of documentation. The top one is a quality manual, the second layer is of procedures, and the third layer is of work instructions. "Records" are in addition to these layers. The second and third layers can make a system bulky and bureaucratic. Hence, it is not surprising why some authors attribute bureaucracy, rigidity, and inflexibility to the QMS. Industry 4.0 applications such as AI-based systems can eliminate the need for these structures. These systems build digital twins, virtual representation of processes and assets. Further, they are capable of making intelligent adjustments based on real-time data and maintain digital records, making "establishing evidence" features of traditional models irrelevant. Artificial intelligence-based systems give rise to lean structures which bring operational efficiencies and make decision-making quicker [11].

Digital solutions provide processes of data maintenance and enable documents to be stored indefinitely, retrieved at any time during the life of a project and after it has been handed over and commissioned. Having a common data environment (CDE), as discussed in chapter "Building Information Modelling and Information Management" on BIM, is essential to achieve a golden thread of information. A digital document information strategy is documented in the quality plan defining ownership and accessibility of information. The BIM execution plan is filed in the quality plan. The ISO 19,650–1 on Information management using building information modelling (BIM) sets out the recommended concepts and principles for business processes across the built environment sector in support of the management and production of information during the life cycle of built assets (referred to as "information management"). These processes can deliver beneficial business outcomes to asset owners/operators, clients, their supply chains, and those involved in project funding including increase of opportunity, reduction of risk, and reduction of cost through the production and use of asset and project information model [7].

4 Quality Management System (QMS)

A QMS is a formalised system for documenting processes, procedures, and responsibilities, managing activities and resources to achieve objectives and prevent non-conformances. The most common approach to implement a QMS is through certification to the ISO 9001 standard. This standard outlines the requirements for QM. Compliance with these requirements is assessed through independent quality audits. Certification to this standard implies that adequate systems are in place to manage quality. Most clients and construction organisation seek the ISO 9001 Standard certification as a prerequisite for any business transaction. Table 1 summarises the benefits of a QMS.

ISO 9001 promotes the adoption of a process approach when developing, implementing, and improving the effectiveness of a quality management system, to enhance customer satisfaction by meeting customer requirements. This approach enables the organisation to control the interrelationships and interdependencies among the processes of the system so that the overall performance of the organisation can be enhanced. The process approach involves the systematic definition and management of processes, and their interactions in order to achieve the intended

Table 1 The benefits of a quality management system

Benefits
Understand own role
Understand the role of others
Provide management tool kit
Meet the organisations expectations
Understand legal, commercial, statutory, regulatory health and safety, environmental, and digital requirements
Control of contractual obligations as the project evolves
Control risk at each gateway
Control resources
Control record keeping
Standardise how a project is delivered and provide heightened governance
Report on performance
Capture key data to make informed decisions
Enhance the organisation's strategic business plan based on empirical data
Prevent errors and reduce rework
Improve efficiency and effectiveness
Check on conformance
Facilitate opportunities to increase customer satisfaction
Provide assurance to internal and external customers
Drive innovation
Maintain market position, reputation and safeguard competitiveness
Document lessons learned, capture best practice and improvement areas, and share knowledge

results in accordance with the quality policy and strategic direction of the organisation. Management of the processes and the system as a whole can be achieved using the plan, do, check, act (PDCA) cycle with a focus on risk-based thinking aimed at taking advantage of opportunities and preventing undesirable results.

This section explains the PDCA cycle, its components, the key activities, and documents that are produced in each stage. As mentioned, PDCA is a risk-based process approach. When risks are detected the organisation can formulate mitigation plans on time. Based on the data captured in the quality management system, it can decide how best to act to minimise the negative impact of risks and explore opportunities. The aim of the PDCA cycle is continuous improvement. Chapter "At The Role of Lean in Digital Construction" on Lean construction theories and processes discusses how digital tools are applied to the plan, do, check, act cycle. It demonstrates how to maximise value and eliminate waste. Lean construction focusses on engaging all stakeholders which, as discussed in Sect. 8 of this chapter, is linked to creating an environment where every stakeholder understands the quality they want. Figure 1 demonstrates how the PDCA works and illustrates how clauses 4 to 10 of the ISO 9001 Standard can be grouped [10]. In each step of the PDCA cycle, there are activities that shall be undertaken, the clauses in ISO 9001 Standard, represented by the numbers in brackets provide the requirements of each activity [10].

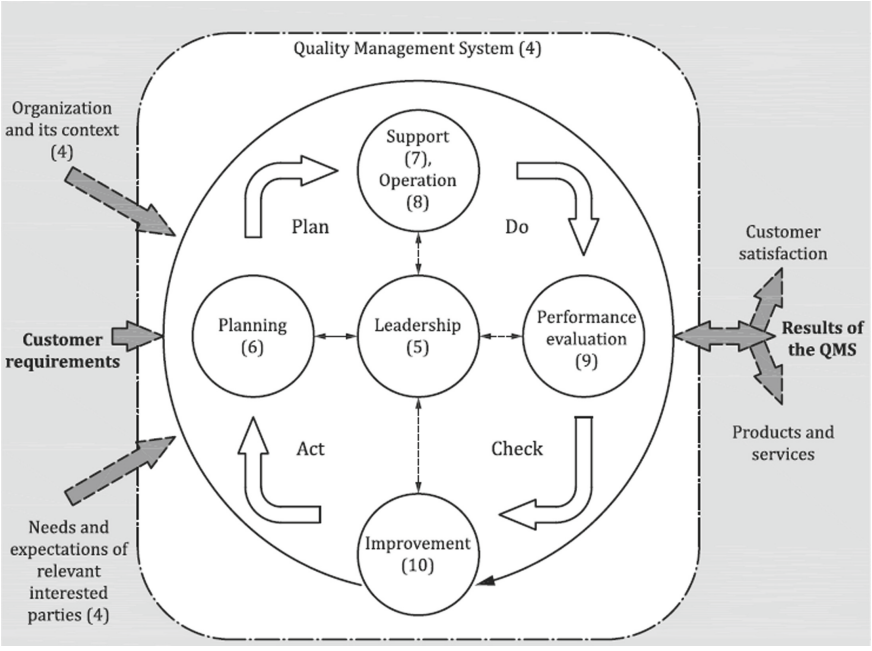

Fig. 1 Representation of the structure of the ISO Quality Standard in the PDCA cycle

(a) **Planning** is the first step in managing quality once the requirements have been established, understood, recorded, and communicated. The objectives of the system, its processes and the resources needed to deliver results in accordance with the requirements are established and risks and opportunities addressed.

The main document produced in the planning stage is the quality plan. It focuses on setting up the project for success. Resources, quality controls, communication, reporting requirements, and mandatory outputs are established in the Plan component of the PDCA cycle. The term resources refer to the people, the equipment, knowledge, and information assets. The ISO standards 9001 quality (2015), 14,001 environmental management (2015), and 45,001 occupational health, and safety management (2018) have clauses covering the aforementioned items. The quality plan describes how an organisation will provide an intended output, whether the output is a product or service [12]. It is a control document that demonstrates how the requirements are met and validated, who is responsible for authorising the release of the outputs, how compliance to the requirements is assessed and how the risks of not meeting them are monitored and minimised. It describes the quality objectives, the management processes/procedures, reporting templates, and systems. It explains how project records are maintained, updated, and shared. Table 2 lists the typical contents of the quality plan which can differ depending on type of product (building) or service (consultancy) delivered.

The quality plan is an ancillary document of the Project Delivery Plan (PDP) or Project/Management Execution Plan (PEP/PMP), it is read in conjunction with other key plans and processes. It is produced by the quality manager. If a quality

Table 2 Contents of a quality plan

Contents of a quality Plan
Quality policy statement and quality objectives
Roles and responsibilities matrix (RAM/RACI)
Competence/training/tools/equipment
Stakeholders' communication management
Management system and processes including quality control
Design development activities/change control
Records requirements
BIM processes
Product identification/fabrication/manufacturing/packaging, delivery, storage/protection, traceability
Testing, commissioning and performance testing, inspections
Continuous improvement
Non-conformance process and control of defects
Auditing and corrective actions
Suppliers' certification (suppliers are required to provide their own quality assurance plans and demonstrate how materials are procured and installations managed)
Lessons Learned/knowledge sharing

manager has not been appointed, it is the responsibility of the project manager to write it and review it with the Project Director. The agreed processes and timelines of quality controls and the certificates required are essential to complete a quality plan. Quality control is part of quality management focussed on fulfilling quality requirements; it is tracking performance against agreed plans and taking the corrective action required to meet the defined objectives [5]. Quality control is the internal checkpoints to let operators and project managers continuously measure the works they are undertaking so that non-conformant outputs are not produced.

The Project Director approves the document before it is circulated to the project team. It is available to all and reviewed throughout the project lifecycle at regular intervals. It is aligned to other key documents including the BIM Execution Plan. Version control and approval are recorded in the quality management system. When using a common data environment, the version control, approval, and record is managed digitally as explained in chapter "Building Information Modelling and Information Management". The latest information is available and there is record of past actions.

People, communication, and reporting arrangements explained in the following three subsections, change as the project evolves. The project team(s) refer to the quality plan for the updated arrangements in order to avoid disruptions and delays in the delivery of the stated requirements.

People

In the planning stage roles and responsibilities, competencies, and training records of the people authorising the release of the outputs are documented in the management system to ensure the requirements have been met. Regular briefings, review of competencies, and training requirements are undertaken as the project progresses through the stages. Upon award resources are selected, a training matrix is held on location and supports in selecting a suitable qualified member of staff for the defined role and responsibilities. It is aligned to the organisation's internal training programme for data analysis on competence, training, and experience.

Communication

The quality manager maintains communication with the client's and project's stakeholders. The project team, contractors, suppliers, internal and external consultants are briefed on the client's requirements and changes are documented. How the quality plan is communicated on digital platforms is determined at the planning stage to ensure the project team is kept informed (for more details on digital communication refer to chapter "Communicating in the Construction Industry").

Contractors, suppliers, and subcontractors must submit their quality plans and quality certifications in the planning stage. The documents required include competency records of those undertaking the works, material certificates, product data, installation instructions, warranties, and quality assurance processes. A schedule of quality induction and quality training aligned with the quality strategy of the project is recorded in their quality plans. Quality plans are maintained in the main project's approved document control system. At the pre-start meeting of a project, the

contractor and subcontractors confirm the quality controls, processes, and qualified personnel required at each project gateway. Approvals and timelines are documented in the quality plan thus the latest information is available to all stakeholders.

– Suppliers' quality plans and filed with the main quality plan of the project. Where goods and material are shipped in for incorporation into the project's products it is necessary to ensure that those materials are of a suitable quality and will not cause a failure of testing further down the line. Suppliers are required to demonstrate origin of products and provide evidence that products comply with the regulations and legislation of the country they are operating in. Documentation of verification and authenticity of products are made available at all times for the quality manager or project team for review. Evidence includes: collaboration and data sharing, standardised systems, performance testing, product stewardship, advice on use and application from competent person, and assurance processes. In Construction 4.0, it is essential that the above data is machine interpretable and recorded in a database to allow an efficient management of information.

Reporting requirements

Reporting on performance supports the Project Director in controlling progress of works and the overall organisation's decision-making process. The reporting requirements are established at the planning stage to ensure that the contents of the report provide the key data that the Project Director requires. Submission dates are aligned to the senior project meetings with the client. The scope, roles, and responsibilities, tools, techniques, and processes are described in the information management plan. It aligns with the quality plan and is in the PDP/PEP/PMP. Digitised report templates enable data analysis in a timely manner, improvements areas, risk, and opportunity are identified and monitored.

Reporting internally to the construction project management organisation on progress of the delivery of the client requirements is mandatory; risk, opportunities, change, commercial, resourcing that may impact the overall appointment are recorded and reviewed at regular intervals as stated in the information management system. Internal key performance Indicators (KPIs) are met as well as the clients to track performance and compliance. Construction organisations are using technology to automate progress and produce reports in real time. For example, Computer Vision is a software used to create a digital twin of the project online accessed through a website. The visual information is analysed by an AI system to extract progress information.

(b) **Do** is the performance of the operations planned and the delivery of requirements. It is applying the systems processes and controls outlined in the quality plan. Changes to the scope, design, and resources are recorded in the quality plan and monitored in online approved systems.

Reporting on risks and opportunities, design changes, cost, schedule, and quality enables the project team to:

– assess how the delivery of the client's requirements are progressing
– make informed decisions to stay on track.

Records of reports and minutes are filed in the approved document control system and made available to the project team at any time. They are included in a database, so they are machine interpretable and easily searchable, and usable where needed.

(c) **Check** is monitoring

– that the works conform to the requirements
– that risk is monitored, and mitigation plans put in place
– that improvements are made.

Two key activities of the checking phase are auditing and digital assurance.

Auditing

Auditing monitors and (where applicable) measures processes and the resulting products and services against policies, objectives, requirements, and planned activities. An audit is a formal activity to independently examine objective evidence and verify conformance to specified requirements. An assessment can consist of a site visit(s) and/or a detailed review of the processes and systems applied to deliver the works. Robust evidence must be provided to demonstrate conformance. An internal audit process adds value to the organisation when corrections and corrective actions have been implemented in a timely manner. A correction is the immediate action taken to eliminate a detected non-conformity. A corrective action is taken to eliminate the cause of a detected non-conformity or other undesirable situations.

Identifying the cause of the non-conforming outputs is key in the auditing process. A root cause analysis may take several days or weeks with technical specialists carrying out a forensic investigation of the non-conformance and making recommendation to avoid re-occurrence.

Internal audit criteria include the organisation's risks, the management system, previous internal and external audit findings, quality, health and safety, and environmental trends. There are other factors to consider, for example, the client's certifications and accreditations. Certifications of the ISO standards 9001 (quality), 14,001 (environmental), 45,001 (Health and Safety), 19,650 (Information Management using BIM), 27,001 (Information Security), 27,007 (Cybersecurity—auditing guidelines) are regarded as a minimum requirement by the majority of clients.

External auditing is essential to get certified and to maintain the certification once it has been awarded. There are surveillance and verification assessments, the latter required for re-certification. The frequency of the audits depends on:

– the certifying body
– the organisation's industry and products/services delivered.

Some certifications are valid for one year, for example, the UVDB (Utilities Vendors Database) issued by Achilles. ISO certifications for quality, health and safety, and environmental may have a cycle of three years.

An organisation's internal audit capabilities are more important than its external audit programmes. External assessors may visit two to three times a year, internal audits take place throughout the year. An organisation's internal audit schedule is indicative of how committed it is to continuously improve the delivery of works.

Continuous improvement is the aim of the PDCA cycle. It focusses on challenging the organisation on *how* the works are planned and delivered, identifying best practice and improvement areas.

Refining the processes to progressively upscale the standards of delivery is managing quality.

Digital Assurance

As mentioned in Sect. 3 assurance is providing confidence to key internal and external stakeholders that the service or product is compliant to the requirements and that risk is controlled. In Industry 4.0, digital assurance is confined not only to testing applications across the Social, Mobile, Analytics and Cloud (SMAC), Big Data (chapter "Big Data and Cloud Computing for the Built Environment"), and Internet of Things (IoT) (chapter "The Role of Digital Twins and their Application for the Built Environment") but there is also a need to assure that the desired business outcome is achieved as a result of the digital transformation initiatives adopted. While quality assurance must support all the digital initiatives, the digital assurance solutions need to go beyond the functional validations needed for SMAC and should encompass the various aspects into them like network capability, interoperability, optimal performance, and enhanced security. This will shift the focus from traditional quality assurance (testing) towards assuring a better customer experience and integrated testing of various embedded software, digital devices, and big data [13].

(a) **Act** consists of improving how the organisation operates based on the audit findings and lessons learned. A non-conformity refines policies, procedures, and supports in identifying the right skills required to deliver a product or service. A nonconformity is not failing, it is not underperforming. It is in fact the evidence that demonstrates what needs to change. The only result is increased operational performance.

It is not uncommon to encounter construction project managers who view internal auditing as a personal interrogation of how they are carrying out the works. Organisations that do not support the auditing processes are not managing quality. If nonconformities are not detected, the project team must redo the works without understanding the cause. The result is an increase in cost, delay in the programme, and client dissatisfaction.

Lessons learned are documented experiences and an organisation's best asset as it matures in the marketplace. Lessons learned workshops happen at regular intervals of the project lifecycle, not only at the close-out stage. Organisations have

a digital platform to store learnings, analyse data, and report on trends. This allows for informed decision making. The organisation shall determine the knowledge necessary for the operation of its processes and to achieve conformity of products and services. Lessons learned on construction projects are twofold: there are lessons identified and recorded for clients and those to be reported back into the construction project management organisation for improvement in similar or future project appointments.

The requirements of lessons learned were defined to:

- Safeguard the organisation from loss of knowledge through staff turnover and failure to capture and share information.
- Encourage the organisation to acquire knowledge by learning from experience, mentoring, and benchmarking.

The procedure and template of lessons learned of a project are contained in the quality plan. Organisations have created an online platform focussed on centralising lessons learned documents. The data becomes easily accessible for project teams who require guidance and best practice identified in previous similar appointments. However, recording learnings remains challenging in most organisations. Section 8 demonstrates the importance of creating an environment that encourages the reporting of errors and not only best practice.

Figure 2 summarises the purpose of managing quality and the key activities of a QMS explained in Sects. 3 and 4.

Fig. 2 Key concepts on quality management (adapted from [14])

5 ISO Quality Standards and Industry 4.0

As discussed in Sect. 4 the QMS in all reputable construction organisations is ISO 9001 certified. ISO 9004:2018 entitled "Quality management—Quality of an organisation—Guidance to achieve sustained success" is an additional standard to sustain a QMS. It is a guidance rather than a certification standard. While ISO 9001 brings an organisation confidence in the quality of products and services, ISO 9004 provides confidence in an organisation's ability to achieve sustained success. ISO 9004:2018 promotes the involvement of top management and requires them to appreciate organisational context, factor in the task and general environment, discern the unique identity of the organisation. ISO 9004 uses a self-assessment approach and assists ISO 9001 with the purpose of making organisational QM system more successful. ISO 9004 is different from ISO 9001 as it transcends product/service quality to "quality of the organisation" and achieving sustained success. However, neither ISO 9001 nor ISO 9004 were developed to respond to Industry 4.0 developments. Consequently, many developments which underpin Industry 4.0 remain unaddressed in both standards [13].

6 Data Analysis and Quality Assurance

Technological advancements in data, analytics, collaboration, scalability and connectivity are driving not just innovation, but true paradigm shifts in manufacturing and the delivery of products and services. With developing technologies such as artificial intelligence and machine learning, big data, cloud computing, augmented and virtual reality, new materials, 3D printing, and the Internet of Things and how these various factors interact businesses need to adapt to a new industrial reality [14]. Key outcome of Industry 4.0 is that people, devices, things, and objects form a highly distributed network (Internet of Things) incorporating the entire process of delivering customer requirements. Cyber physical systems, one of the concepts of Industry 4.0 can communicate and cooperate through the Internet of things and offer relevant data and information in the network [11]. Technology provides an environment where 'human beings, machines, and resources communicate with each other as naturally as in a social network' [15]. Organisations have physical and virtual data available; processing data happens at all levels of the organisation allowing for heightened governance and re-focus on quality assurance. This supports in reducing errors, increasing productivity, and improving communication flow. Communication with all key stakeholders is key and it is explored in Lean Construction (chapter "At The Role of Lean in Digital Construction"). In Sect. 8 of this chapter, the benefits of BIM in enabling communication and collaboration at every project level are demonstrated.

Owing to Industry 4.0, the modern quality is about gleaning rich insights from large data and making accurate predictions to understand customer needs better.

Since customer requirements are fluid and changing, making accurate predictions is of utmost importance. This critical foundation of identifying and managing customer requirements is missing in the current QMS models. One notable exception is ISO 8000 standard, entitled "Data Quality" meant for facilitating the exchange of quality data. The standard addresses how data is encoded and formatted to deliver quality information reliably. It defines quality data as "portable data that meets stated requirements". The standard makes it possible to contract for quality data and identify vendors and partners who can deliver quality data. The importance of this standard is particularly highlighted against the backdrop of Industry 4.0 which builds digital processes and supply networks. Exchanging quality data with partners in the network is the cornerstone of value-adding collaborations. ISO 8000 discusses data governance and acquisition of quality data and information; however, it neither guides nor requires organisations to use data for customer and market segmentation, creating new product and process differentiation, developing new core capabilities, databased risk management, and creating unique strategic competitive advantages [11].

7 Quality Management System and Industry 4.0

Industry 4.0 represents the latest developments that bring fundamental changes in organisational processes, roles of employees, and the overall workplace. QM models and Industry 4.0 share a common objective, that is, improving organisational performance [16]. The article "Quality management in the twenty-first century enterprises: Research pathway towards Industry 4.0" by Gunasekaran and Subramanian [17] discusses how the QMS needs to be updated to capture the benefits of Industry 4.0. Some of the key aspects of lack of alignment are discussed in this section. Industry 4.0 developments have taken place on the technical side of the organisation. Automation, intelligent systems, and AI dwindle the human role in the workplace. Further, these developments are exploitation-oriented, which means they promote efficiencies and streamline processes. An imbalanced emphasis of Industry 4.0 on the technical side only, reduces employee cognitive engagement and perceived meaningfulness of job, which can entail boredom, errors, and burnout. This, in turn, reduces the quality of work and adversely affects job satisfaction. Bringing mindfulness to modern jobs to make people more cognitively involved and increase their perceived value of job needs to be addressed in future quality models.

Industry 4.0 comprises the latest developments in engineering, IT, nanotechnology, cloud computing, and artificial intelligence. These developments make some types of skills obsolete and others more relevant. Managing the required repertoire of skills, knowledge, and capabilities is essential to harvesting Industry 4.0 benefits. These knowledge bases exist not only in explicit and tacit resources but also in social networks. Traditional QM models focus on the development of human resources which is a small subset of intellectual capital and an insufficient

requirement for managing knowledge-intensive Industry 4.0. The need, therefore, arises for traditional QMS models to be updated to manage the human, social, and intellectual capital of firms on a systematic basis [18].

Building on big data, AI, and advanced analytical approaches, the modern concept of quality is about creating unique customer experiences. Virtual reality facilitates product/service customization that appeals to the customer. Defining and managing quality for fluid and impermanent customer requirements need better consideration in QM models. Building on the analysis of big data, a challenge for managers is to make accurate predictions about what actually matters to the customer. Making right predictions based on big data is the new face of customer service quality and needs to be addressed in future QM models. Industry 4.0 entails lean structures. Traditional QM models, which aim to create a systematic approach to the management of quality, develop structures which usually take the form of policy documents, procedures, instructions, records, and traceability mechanisms all of which make management systems bulky. Industry 4.0 renders these structures and processes redundant as it uses real-time data and artificial intelligence to determine the most efficient way to task execution and decision making. Finally, Industry 4.0 develops new business models, such as complementors' and "business ecosystems" where multiple firm co-create value [11]. These organisations work in an integrated and seamless manner to create value for the customer. The management of operations of networked firms is different from the supplier management required in the current QMS. Future QMS needs to address this transition. It should be noted that although traditional quality models do not hamper the adoption of Industry 4.0, but they do not address it either. Industry 4.0 has mainly affected the technical side of the organisation. The social side needs to be developed and aligned to the technical side to reap maximum benefits from Industry 4.0 developments. The developments related to the social side include, but are not limited to, mindfulness, intellectual capital management, psychological ownership, and perceived significance of the job. Further, developing human and intellectual capital can produce a synergistic effect in harnessing value from the technical side. Addressing the social side and making it aligned with the technical side is the area that a QMS can address [11]. Nonetheless, Industry 4.0 has propelled the management of quality at the top of construction organisations' priorities. Section 8 explains how QMS, big data, and sophisticated digital tools to manage quality are meaningless without having a robust quality culture in the organisation. Investments in Industry 4.0 developments will only be worthwhile in an environment built on quality.

8 Building a Quality Culture

All clients want products and services that meet their requirements and all organisations are committed in delivering them. Organisations believe they manage quality. They have quality assurance resources, quality controls, and management

systems in place. They demonstrate that quality is an integral part of all their operations. Every director, manager, and operative believes they deliver quality. Yet there is error and rework in most construction projects.

There is a misunderstanding and the danger that having the resources and a management system, quality will be delivered. Quality assurance, quality management, and quality controls are also thought to be the same. In these circumstances, quality is treated as an add-on to the main operations of the organisation. It is taken for granted. It is the subject that is set aside. Directors only become aware of *quality* when they hand over the project to the client, confirming that they have indeed delivered a quality product or service with a rework list in hand. Managing quality is more than conforming to a set of requirements, having quality certifications, resources, policies, and management systems. It is the result of a carefully constructed cultural environment [3]. Quality is not a standalone subject that is managed and measured independently from other key management activities in the organisation. It is interwoven in all the other construction disciplines, functions, and operations. How all these disciplines are managed is rooted into the quality culture of the organisation.

The leaders of an organisation are the first triggers of making quality equal to safety and profit. They are custodians of the quality culture. Doing things correctly every time, preventing errors, and building successful relationships with colleagues, suppliers, and clients are the fabric of a strong quality culture. Employing the right people and providing innovative solutions for the delivery of products and services are only part of it. It is therefore essential to create a culture and use soft skills to communicate it within the organisation (see chapter "Communicating in the Construction Industry") and lead it (see chapter "Digital Leadership for the Built Environment").

Organisations' values, policies, and strategies are the starting points that demonstrate how quality is positioned in the organisation. They are not enough to make quality certain.

A quality culture is characterised by:

- leaders who believe that quality is equal to profit
- providing clear roles and responsibilities
- understanding the needs of internal and external customers and stakeholders
- controlling other's input into your work
- encouraging open and honest reporting
- communicating objectives at all levels in the organisation.

Leaders create space to enable their workers to *continuously improve* their products and services. Chapter "Digital Leadership for the Built Environment" on Digital Leadership discusses this key aspect in more detail.

Organisations with a strong quality culture are the most reputable, attract the best talent, have a lower staff turnover, enjoy good profits, and have a healthy future. In the construction, industry quality is still sacrificed to gain time and cut costs. The results of poor quality as demonstrated in this section are fatal.

8.1 Behaviours and Attitudes

Quality is doing the right thing when no one is looking [19].

Having the right attitude and taking pride in your own work make the management of quality successful. Everybody is responsible for quality from the Board to the operative on site. "You must have pride, ownership, and responsibility that you are building a safe building" [9]. It is no use saying, "we are doing our best". You have got to succeed in doing what is necessary' (Churchill) [20].

8.2 The Challenges of a Project Manager

A project manager is challenged every day by quality, time, cost, and risk. There is intense pressure from the client to deliver on time and on budget. Quality for a client is certain. It is the leaders of the construction project management company who drive the right behaviours and create the environment for a project manager to be able to focus on quality as much as on cost and time. In many construction organisations, this is not the case organisations and this is not the case. The "on budget and on time" philosophy is embedded in their operations; quality is not. Digitised quality controls, data analysis, and reporting create a new approach to quality assurance. They allow for increased transparency in reporting, tighter control of what is being produced and delivered, and having the evidence to demonstrate it. However, ahead of digital innovation in an organisation a robust quality culture is required to enable excellent service of a product or service delivery.

Quality becomes difficult to manage when it is misunderstood. It is squeezed and stretched resulting in the construction project management organisation not delivering what the client wanted. In this type of project environment, quality controls and auditing are perceived as additional work and a disruption to the daily operations on site. If operating in an environment with a poor quality culture, the most skilled and talented construction project manager is channelled to focus on their employer's priorities. When the project is completed and handed over, the client undertakes a benefits realisation exercise to review their investment. An assessment of the contractors' and consultants' performance is also completed, quality being the main denominator of the assessment. No quality means no repeat business. Figure 3 demonstrates the baselines of a project. Retaining customer focus while managing deadlines, controlling risk, cost, and quality throughout the project lifecycle is challenging for the project manager. Change driven by the client or by external factors and bodies adds pressure to the project team resulting on quality being compromised. Good project management is the ability to control the key baselines, monitoring the risk of not fulfilling requirements, and providing solutions in order to deliver the product or service the client expects. Working in an environment based on collaboration and sharing information on time minimises the

Fig. 3 Association of Project Management body of knowledge

daily challenges of the project manager. The case study in Sect. 9 shows that BIM was used to for coordination and communication across all levels of the project. This allowed for complex issues to be identified and resolved before construction works began without compromising on quality.

8.3 Eliminating Fear of Mistakes

An environment that encourages workers to be open and honest about making mistakes without fear of being reprimanded allows a project team to perform. If errors are not reported, rework is certain as the root cause was not identified. There is a feeling in the project team that there are many quality problems, they feel their work is not good enough, resulting in low morale which causes poor performance. Avoiding mistakes start by reporting what is really happening. Non-conformances in an organisation that has quality pulsating in all its operations are learning opportunities to refine its systems and processes. Quality becomes free as rework is minimised or eliminated completely.

In a study with Google on how an organisation's performance improves five factors were identified:

- having clear goals
- having supportive colleagues
- doing personally meaningful work
- believing that your work makes a positive impact
- feeling psychologically safe to report a mistake [21].

Every error, every flaw, every failure, however, small, are a marginal gain in disguise [22]. Learning lessons requires humility, courage, and innovation [9]. Creativity, innovation, and knowledge sharing are the results of an organisation that encourages errors to be reported and new ideas to be tested, however, unsuccessful they might be.

8.4 Building Successful Relationships with Colleagues, Suppliers, and Clients

Collaboration is required when managing different goals, objectives, expectations, cultures, and behaviours between organisations. This aspect is also covered in chapters "Professional Impact in the Construction Industry" and "Managing Relationships in the Construction Industry". Agreeing on joint objectives, structures, resources, processes, roles, and responsibilities enables the interested parties to benefit from the business relationship. The first step is understanding the internal functions' aspirations and needs. It sets a solid base to find the right clients for your own organisation and build a successful relationship. Some construction companies have the ISO 44,001 certification on collaborative business relationships. It provides a framework and a set of requirements for successful collaboration. There are eight stages in the lifecycle of a collaborative relationship from adoption to disengagement:

- operational awareness: establishing the operation's propensity for collaboration;
- knowledge: evaluating specific collaborative benefits and business case;
- internal assessment: assessing the operation's capability to collaborate;
- partner selection: establishing an appropriate selection process;
- working together: establishing a joint governance model for collaboration;
- value creation: establishing a joint process for continuous improvement;
- Staying together: managing, monitoring, and measuring the relationship over time;
- Exit strategy activation: establishing a joint approach to disengagement [23].

Collaboration between the participants involved in construction projects and in asset management is pivotal to the efficient delivery and operation of assets. Organisations are increasingly working in new collaborative environments to achieve higher levels of quality and greater re-use of existing knowledge and experience. A significant outcome of these collaborative environments is the potential to communicate, re-use, and share information efficiently, and to reduce the risk of loss, contradiction or misinterpretation. True collaborative working requires mutual understanding and trust and a deeper level of standardized process than has typically been experienced if the information is to be produced and made available in a consistent timely manner. Information requirements need to pass along supply chains to the point where information can be most efficiently produced, and information needs to be collated as it is passed back. At present, considerable resources are spent on making corrections to unstructured information or incorrect management of information by untrained personnel, on solving problems arising from uncoordinated efforts of delivery teams, and on solving problems related to information re-use and reproduction. These delays can be reduced if the concepts and principles within this document are adopted. The Get it Right Initiative objective is focussed on engaging all stakeholders to create a working culture that gets it right from the start eliminating error from inception, to

completion [1]. Stakeholder engagement is key in Lean Construction (chapter "At The Role of Lean in Digital Construction").

8.5 Analysing and Reporting Customer Feedback

The organisation shall monitor customers' perceptions of the degree to which their needs and expectations have been fulfilled. The organisation shall determine the methods for obtaining, monitoring, and reviewing this information [10]. Keeping an open dialogue with clients, recording what they think, reporting it to the decision makers of the organisation is key to continuously improve products and services which is key in Lean Construction (chapter "Information Visualization for the Construction Industry"). Performance shall be monitored throughout the project lifecycle, and if required, improvements made based on clients' feedback. The online management system provides the guidelines and templates of the customer feedback survey form. The Project Director or Board member shall meet with the client to review performance. The survey may include questions on the project management service, value for money, reporting, communication, people's competencies, and added value. The results of the survey shall be analysed to identify the team's strengths and areas of improvement. The aim of customer feedback is to ensure the project team, and the organisation is on track to deliver the client's requirements. Data on customer feedback and quality shall be collated throughout the year on digital platforms in order to analyse trends. This enables informed decisions to be made. A report to the Board with recommendations of improvements shall be submitted.

9 BIM and Complex Construction Projects

This section demonstrates how BIM can support in creating an environment of collaboration and communication across all levels of projects where quality becomes the responsibility of all. The Hanover Development of the Great Portland Estates plc is a project consisting of four buildings being partly built and partly refurbished in a heavy pedestrianised area of Central London with limited space, historic façades and with the live Crossrail site underground connecting the City's East and West. It has been described as an iceberg as there is as much construction going on underground as there is overground. Despite the Hanover Development project operating with one project team, each building had its own team of project managers, specialist engineers, and suppliers interacting with teams delivering Crossrail, London Transport Authorities, and the public. Planning and coordinating with all teams of the four buildings in advance was key to the success of the project. The project team developed the Hanover scheme on a data rich information modelling environment, coordinating and constructing the entire project virtually

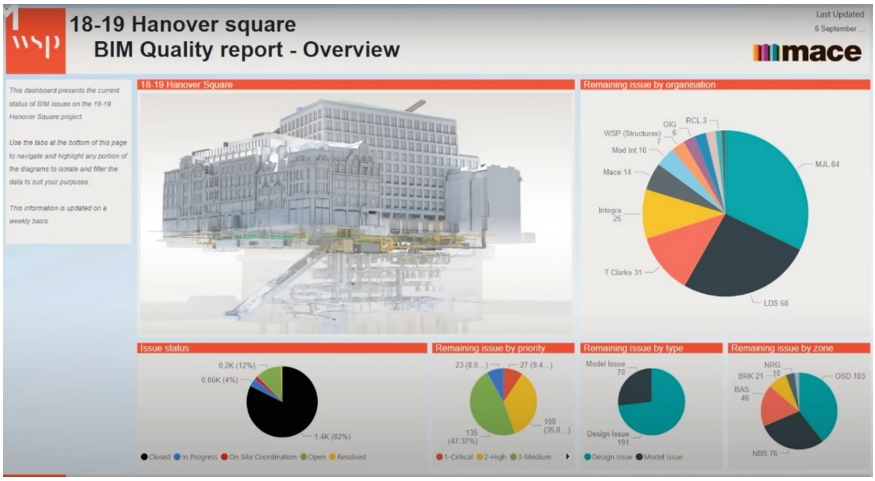

Fig. 4 BIM quality dashboard—Hanover Development

and resolving any issues before the works commenced on site. A digital tool (BIM Track) was used as a central hub for coordination and communication of key information across all teams. Uniting every member of the team on one platform was the success factor, it democratised the sharing and communication of information relating to the project. The tool was used to log clash items, identify where the issue was, and track the issue through to resolution in design coordination sessions. This approach created a greater level of collaboration and interface with all teams. A BIM Quality Dashboard, customised for the Hanover scheme to suit the teams' requirements, reported on the status of issues to be resolved. The process of identifying and resolving issues became everyone's responsibilities, not just the design teams. BIM changed the dynamics of how the teams interfaced. The project was operating with different programmes and as changes happened every day, handovers in every section of the buildings became challenging. BIM allowed a collaborative approach to production and delivery. It enabled a proactive approach establishing the right behaviours which generated a time saving of 20–30% in the collaboration process. BIM enabled the project team to manage numerous interfaces, a key aspect of many construction sites [24] (Fig. 4).

10 The Cost of Poor Quality

The cases in this section illustrate the devastating consequences of not managing quality. There is an urgency for construction leaders to build a quality culture and show what the industry can do and build confidence in the reputation of the industry.

10.1 Grenfell Tower

The Grenfell Tower tragedy on 14th June 2017 was due to quality and safety not being checked. Safety defects allowed a small fridge fire to spread and engulf the 24-storey building, killing 72 people. The UK Government invited Dame Judith Hackitt to review the building regulations and fire safety of high-rise buildings and get to the cause of the tragic events. Hackitt, a chemical engineer with no construction background would provide a fresh insight into what is happening in the construction industry.

Hackitt's report on Building a Better Future highlights that a cultural change is required ahead of a regulatory change to deliver a building that is fit for purpose and safe for the end user. The report highlighted the key issues in the industry today:

- lack of leadership
- poor record keeping
- changes not recorded
- design changes not reviewed
- lack of system-based approach to regulations
- lack of integration of services and cross referencing
- lack of responsibility, ownership, and accountability
- management framework is too prescriptive and written in silo.

She recommended introducing positive incentives and punitive actions for those who try to game the system. A risk-based, regulatory and outcome-based framework that encourages ownership and accountability, overseen by a regulator, is required. Those undertaking the building works need to demonstrate that they know what they have to do and are doing all they can to manage and reduce risk. Innovation is encouraged and overseen by a regulator. The design is checked that is safe and the accountability stays with who puts up the building. A digital approach is required. Building owners, occupiers, and financiers will demand proof of quality and competence [9]. Automated and semi-automated data collection has great potential to ease the burden of achieving regulatory compliance checking. The project "Utilising Innovative Methods of Data Capture for Regulatory Compliance Checking" undertaken by the University of Cardiff, demonstrated some concrete steps that can be taken more immediately to make meeting compliance goals more efficient. These are: (a) examine ways in which compliance data can be captured digitally—even if the collection process itself is manual; (b) having an organised digital repository of compliance data will be invaluable because building owners are increasing being called upon to build a "golden thread" of their assets data; (c) once this is established, where possible, attempt to automatically collect compliance data using sensors and other technologies, because this paves the way for automated or semi-automated assessment; (d) if automatic collection of data is not possible, consider ways in which the process can be conducted by semi-automatically or manually, but by individuals that are already on site. Moving to a model where the data collection and assessment of the data are distinctly

separate. This makes more efficient use of those able to assess compliance results and generally improves productivity. The project was part of the D-COM Network. The D-COM network was formed to drive forward the adoption of the digitization of regulations, requirements, and compliance checking systems in the built environment [25].

10.2 Edinburgh Primary School

In 2016 Edinburgh's Oxgangs Primary School wall collapsed. Nine tonnes of masonry fell in an area where children stand or pass through. There was one fatality, but the number would have been higher had it happened at a busier time of the day. A lack of quality controls in the contractor's processes was the main cause. Three defects were found:

- not enough wall ties
- the wrong type of ties was used
- wall cavities were not uniform.

The primary cause of the collapse of the wall was poor quality construction in the building of the wall which failed to achieve the required minimum embedment of 50 mm for the wall ties in the outer leaf of the cavity wall. The poor quality relates to all three of the following aspects:

- the quality assurance processes used by the sub-contractor and main contractor to confirm the quality of the construction of the walls
- the direct laying of the bricks and the positioning of the wall ties
- the direct supervision of the laying of the bricks and the positioning of the wall ties.

All three issues were the responsibility of the design and build contractor in charge of the site [26].

10.3 Richmond House, South London

In 2019 a fire destroyed a block of 23 flats in a four-storey building. Unlike Grenfell Tower, Richmond House was not a refurbished council block of flats dating back to the 70 s. It was part of an award-winning modern development. Its cladding was signed-off. It was safe but the walls had defects. A London-based consultant who inspects homes for new safety checks required by banks found that behind the cladding the materials were incorrect and non-compliant. He confirmed that "it is all about costs, getting cheap labour and cheap materials, and putting the building up as quickly as possible" [27].

10.4 The Get It Right First Time Initiative (GIRI)

The cost of quality is the cost of doing things wrong. The construction industry continues to report a loss of income due to rework. The findings of continuous research by GIRI are all quality linked. GIRI is an organisation composed of industry experts and businesses dedicated in eliminating error from inception to completion of a project. Error is costing the UK construction industry £10–25 billion per year [1].

The main root causes of error are:

- Poor culture in relation to quality
- Inadequate planning
- Late design changes
- Poorly communicated design information
- Poorly coordinated design information
- Inadequate attention paid in the design to construction
- Excessive commercial (financial and time) pressure
- Poor interface management and design
- Ineffective communication between team members
- Inadequate supervisory skills.

11 How Can You Make a Difference

Quality is what makes or breaks an organisation. The quality of products, services, and processes is essential to achieve sustainable economic success and to ensure competitiveness. There are devastating consequences of not managing its such as loss of life, reputational damage, loss of income and employees, fines, and gaol sentences.

The quality maturity matrix (Table 3) developed by P. Crosby in 1979, provides guidelines on how to assess the organisation's understanding of quality and how to begin building the right environment. Digital systems and techniques are easier to implement once the leaders of the organisation realise the benefits of managing quality. Rework is diminished with the aim to eliminate it and increase profit [3]. As progression is being made with digitisation, there is opportunity to re-establish a quality culture throughout the industry. Section 9 demonstrated how BIM fosters the right behaviours and supports in managing a multitude of disciplines and interfaces in a complex construction environment. Technology is part of it, it is the organisation's commitment to quality that makes the delivery of a quality assured building happen. ISO standards and the QMS model may have not been updated to capture the benefits of Industry 4.0, however, their principles and purpose remain and do not prevent technology to be applied. Industry 4.0 has created an opportunity for construction organisations to re-focus on creating a quality culture.

Table 3 Quality maturity matrix

Management categories	Stage 1 uncertainly	Stage 2 awakening	Stage 3 enlightenment	Stage 4 wisdom	Stage 5 certainty
Management understanding and attitude	No comprehension of quality as management tool	Not willing to provide resources and systems for quality management	Understanding of the benefits of quality management	Understanding that everyone is responsible for quality	Quality is considered as important health and safety and profit
Quality organisation status	Inspection of works is not part of the processes. Emphasis on appraisal and sorting	A stronger quality leader is appointed but main emphasis Is still on appraisal and sorting issues	Quality resources report to decision makers and have a senior position and able to engage with key stakeholders	The Quality Manager has a senior position and is engaged with all functions of the organisation and to enable prevention	The Quality Manager is one of the decision makers
Problem handling	Problems are dealt with as they occur. Blame culture	Resources focus on sorting out the quality issues, without thinking about the long-term solutions	Quality trends and corrective actions are reported to the Board. There is open and honest communication	Problems are identified in the early stage of delivery. Prevention and improvement are planned	Preventive measures are planned and actioned. Quality problems are unusual
Cost of quality as % of sales	Reported: unknown Actual £20–25b in construction	The reported figure is not actual	The figure reported is much higher than expected. The actual figure	Reported and actual figure diminish	Reported and actual figure is the same
Quality improvement (QI) actions	No understanding of QI	Attempts to implement QI activities, more reactionary than part of the corporate culture	A management system, resources, forums, internal audit schedules are set up	Resources, training, and systems are refined in order to make quality certain	QI is standard practice across all functions of the organisation
Summary of the organisation's quality position	No understanding of quality problems	No understanding why there are always problems with quality	There is support from decision makers and quality is becoming as important as profit	Prevention is better than fixing the quality problem	Quality is certain

References

1. Get it Right Initiative (GIRI). https://getitright.uk.com. last accessed 10/02/2021
2. Singh, M., Khan, I.A., Grover, S.: Tools and techniques for quality management in manufacturing industries. CONFERENCE on Trends and Advances in Mechanical Engineering (TAME 2012), YMCAUST, Faridabad, (2012)
3. Crosby, P.: Quality is free: the art of making quality certain. McGraw-Hill Inc., New York (1979)
4. APM Body of Knowledge, 7th edition, Association of Project Management (2019)
5. ISO 9000:2015 Quality management systems—fundamentals and vocabulary
6. Crosby, P.: Philip Crosby's Reflections on Quality. McGraw-Hill Inc., US (1995)
7. ISO 19650–2:2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)—Information management using building information modelling—Part 2: Delivery phase of the assets
8. Cooper, R., Nelson-Williams, R., Kitt, G., Recan. J., Torres. M.: Global Construction Disputes Report 2018, Contract Solutions, Arcadis (2018)
9. Hackitt, D.: Building a Safer Future—Independent Review of Building Regulations and Fire Safety. APS Group, London (2018)
10. ISO 9001:2015 Quality Management Systems Requirements
11. Asif, M.: Are QM models aligned with Industry 4.0? A perspective on current practices. J. Cleaner Prod. (Prince Sultan University, Saudi Arabia) (2019)
12. ISO 10005:2018 Quality Management—Guidelines for Quality Plans
13. A. How Digital Assurance is Different from Traditional QA Cigniti Technologies (2016)
14. Zaidin, N.H.M., Diah, M.N.M., Po, H.Y., Sorooshian, S.: Quality management in industry 4.0 Era. J. Manag. Sci. **8**(2) (2018)
15. Srivastava, A.: How Digital Assurance is Different from Traditional QA Cigniti Technologies (2016)
16. Lee, I., Lee, K.: The Internet of Things (IoT): applications, investments, and challenges for enterprises. Bus. Horiz. **58**, 431–440 (2015)
17. Gunasekaran, et al.: Quality Management in the 21st Century Enterprises: Research Pathway Towards Industry 4.0 (2018)
18. Kagermann, H., Wahlster, W., Helbig, J.: Recommendations for implementing the strateg. ic initiative INDUSTRIE 4.0—Final report of the Industrie 4.0 Working Group (2013)
19. Ford, H.: Wheels for the World: Henry Ford, His Company, and a Century of Progress, Brinkley Douglas, Penguin (2004)
20. Churchill, W.: The Power of Words, His remarkable life recounted through his writings and speeches, Martin Gilbert, Da Capo Press Inc (2014)
21. Rozovsky, J.: The five keys to a successful Google team, Re:work With Google (2015). https://rework.withgoogle.com
22. Syed, M.: Black Box Thinking Penguin (2015)
23. ISO 44001:2017 Collaborative business relationship management—requirements and framework
24. The B1M, Is This London's Most Complex Construction Project? Construction Video Channel. https://www.youtube.com/watch?v=LlPsbZusdqo. Last accessed 10/02/2021
25. Beach, T.: Utilising Innovative Methods of Data Capture for Regulatory Compliance Checking Report for Industry 2020 Cardiff University (2020)
26. Cole, J., Maccartney, S., Phillips, C.: Report of the Independent Inquiry into the Construction of Edinburgh Schools, ECC (2017)
27. Apps, P., Heath, L.: Defective' cavity barriers 'contributed nothing' to slow fire in Worcester Park blaze, Inside Housing (2020)