MATERIALS 4.0

A ROLE FOR STANDARDS

This report is commissioned by the Henry Royce Institute for advanced materials as part of its role around convening and supporting the UK advanced materials community to help promote and develop new research activity.

The overriding objective is to bring together the advanced materials community to discuss, analyse and assimilate opportunities for emerging materials research for economic and societal benefit. Such research is ultimately linked to both national and global drivers, namely Transition to Zero Carbon, Sustainable Manufacture, Digital & Communications, Circular Economy as well as Health & Wellbeing.

HENRY ROYCE INSTITUTE

Ferroday LTD

UKRI Engineering and Physical Sciences Research Council

Materials 4.0: A Role for Standardised Digital Representations

1. Introduction

The aims and objectives of Materials 4.0 to achieve a data-centric, digital approach to innovation, characterisation and manufacture in the materials sector are the same as have been identified in other industrial sectors; notably auto, aerospace, construction, oil & gas, chemical process plant, cutting tools, and more recently in nuclear. Increased digitisation in engineering and manufacturing creates new opportunities and new demands in processing, procurement, design, test, service, recovery and re-use. However, each engineering software system has its unique internal method of representing the data that it processes and so this digital product information cannot be understood and processed directly by other systems that have different internal representations. Incompatibilities in the digital representation of engineering data transferred between different software systems results in extra costs from delays, re-working and lost opportunities. Avoidance and mitigation of these costs requires ensuring that the digital representation of the content of the message will be understood and can be useable by the receiving software system. Furthermore, the lifetime of many products is usually greater than the lifetime of engineering software systems. So, there is an additional requirement to ensure that digital product data is retained in a form that can still be *computer-understandable in this form* many years after the originating system is obsolete, or else no longer available, and so avoid the increasing problem of legacy data.

Global collaboration over the last thirty years had developed a consensus for managing the digital representation of relevant engineering data for the industrial sectors identified above by the use of International Standards. These Standards provide specifications for the digital representation of engineering data in a form that captures the semantics of the information that the data represents in a form that is independent from proprietary software. The technology that these Standards describe is well established and reliable and can be confidently adopted to realise some of the aims and objectives of Materials 4.0. This report outlines the benefits of this approach and summarises some of the costs for not adopting a strategic and technical approach to interoperability. The main features of this global technology are described, and a road map is proposed for the research, education and training activities that could be adopted to achieve the objectives of Materials 4.0.

2. Product data technology

2.1 History and origins

Product data technology is a convenient name for the collections of methods that have been developed by the global engineering community for the digital representation of engineering data to describe products, process and properties. The origins of this technology arose in the 1980s from the effects of the expansion of supply chains in the auto and aerospace sectors and the adoption of computer-aided engineering (CAE) and computer-aided design (CAD). Since each CAE and CAD system has its own internal way of representing the data that it processes this data representation could not be processed by a different system in a network without some means of translation of the communication. In a large network of different systems, or with new members of the network, the maintenance of individual one-to-one translators between every system in the network is very expensive and not sustainable (Figure 1). The alternative of using native-file transfer is even more expensive. The USA, Germany and France developed national solutions to the problem by developing standards for the independent representation of data for CAD, but it was quickly realised that this was an international problem that needed an international solution. The ISO Technical Committee 184, Sub-committee 4 'Industrial Data' (ISO/TC 184/SC4) was established in 1984 with support from the UK, France, Germany and USA in order to develop the technology and standards for the digital representation of *all* engineering product data, not just for CAD. The ISO committee now has 19 contributing states as members, 18 observers and has several working groups to further advance and develop the technology. The technology of ISO/TC 184/SC4 (SC4 technology) has also been adopted by other ISO Committees. The UK mirror committee for ISO/TC 184/SC4 is the BSI Committee AMT/4. Many of the important standards were developed here and members of the BSI Committee continue to play a major role in the latest developments of the technology and the standards.

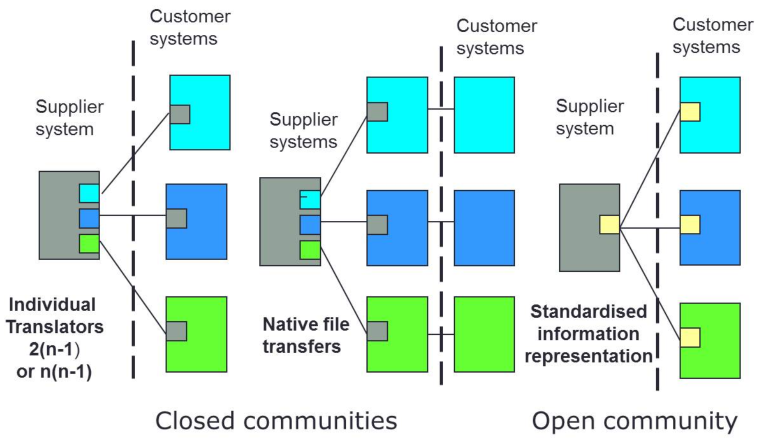

Figure 1 Strategies for the exchange of engineering product data between different systems in a supply chain.

2.2 Outline principles of product data technology

The solution adopted by the global engineering community to the problems of digital *interoperability* and *through-life management* of engineering information is to specify the description of the product and its properties by non-proprietary, computer–understandable *information models*. These models are described in International Standards to provide a common global language for the digital representation of engineering information. They are the modern equivalent of standardising the description of screw threads and the sizes of nuts of bolts in the 19th Century. These specifications also can form the basis for the quality control and quality assurance of the digital engineering data, just as with any other engineered product.

An *information model* is a formal description of types of ideas, facts and processes which together form a model of a portion of the real world, *and* which provides an *explicit* set of rules for the interpretation of the information. If the information model is written in a computer-sensible representation, then it has the additional quality of being computer-processable. The structure of a sentence in a natural language and the numerical form of a calendar date are examples of standardised information models. Placing data items into the appropriate places in the model structure creates an *instance* of a standard model to convey a particular piece of information: words in a sentence or numbers in the numerical representation of a calendar date. So, an information model for a particular application can be re-used repeatedly with appropriate data.

The representation of information for digital communication and archiving then requires three components:

- data items to represent the information content.
- a dictionary to define the meaning of the data items.
- a computer-processable information model to define the structure of the data with explicit rules for how the data should be interpreted.

Everyone in a communication process must use the same information model and the same dictionary in order to avoid misunderstanding.

3. Benefits and opportunities

The information models specified in the ISO standards could provide new opportunities and new business models for the application and presentation of materials information. A rigorous management of digital information should have high priority in any organisation and the standards described in this report can support the tools to achieve this objective.

An important benefit from digital specifications that are based on common information models is that several standards can be combined to provide opportunities for new business models and new methods of working. Several have been combined to form an integrated system for manufacturing by machining, for example. A 3-D CAD model of a part forms the basis for the design of the tool path, the tool path is the basis for the machine control instructions, data on the assembly of the cutting tool and its exact dimensions can improve the tolerances and avoid collisions. These standards have then been integrated with other standards for the output of the machining data and the quality assurance of the result to provide a digital twin of the machining process. A standard for materials and product characterisation could provide more opportunities to integrate materials information into digitally controlled machining and other manufacturing processes

Big Data is a common theme for a new opportunity in the new digital era, but it comes with constraints. Big Data is characterised by:

- Variety – the collection of data will arise from several sources
- Velocity – the speed with which the data can be generated poses problems for its management
- Variability – inconsistencies in the data can hamper its combination
- Veracity – the quality of the data can vary, and this will influence the reliability of the outcome
- Complexity – if the data comes from different sources then they have to be able to be combined in a way that enhances the value of the whole collection

It is this last point that controls the whole feasibility of the Big Data paradigm. There is an obvious benefit from a standardised representation that defines the same semantics and syntax for each set of information to be combined.

For the development and exploitation of new materials, new users will need full information in order to have confidence in their use for new applications. This information will be generated in many different locations and will not be confined to simple properties. A common method of representation would provide the resources to enable information on new materials from different sources to be represented by the same specification and to be collected together.

New opportunities arising from use of standards for digital representations could therefore include:

- Dynamic information management – data management throughout the complete product life cycle
- Block chain monitoring – to conserve data integrity
- More effective recovery and recycling – to conserve resources
- Lifetime identification of products – for repair and modification
- More complete information for new processes – such as additive manufacturing
- Managed input to AI systems
- Representation of knowledge
- Conservation of research data for re-interpretation as new paradigms emerge

4.0 Costs of interoperability and legacy data

The costs of not adopting strategic and technical approaches to the management of digital product and process data can be categorised as: avoidance costs, mitigation costs, delay costs and opportunity costs.

4.1 Interoperability and legacy costs

Examples of costs that should be avoided and that are incurred as a result of interoperability between software can include:

- The costs of purchasing, maintaining and training for redundant CAX systems
- The costs of maintaining redundant paper systems for exchanging information
- Outsourcing translation programmes to third parties
- Investments in in-house programs, such as ad-hoc point-to-point translators to address interoperability issues
- Training and software maintenance
- Costs of internal research and development for internal standards and methods for integration between internal systems
- Managing the paper trail
- Incurring labour costs for re-entering data between different systems and between paper records and digital systems
- Searching for information and validating it
- Searching for information for maintenance
- Connecting operation and maintenance costs to records of equipment and plant that have not been updated.

4.2 Mitigation costs

Mitigation costs stem from ex-post activities needed as a response to interoperability problems and they are often the largest portion of the costs of interoperability. Most mitigation costs result from the re-entering of data from electronic or paper files into multiple systems. They may also include scrapped material costs because of lost, inaccurate or incomplete information. There have been several examples where materials and products had to be re-tested because the original data was incomplete, or the records had been lost or forgotten. There will be a loss of knowledge from the accumulation of historical information of processes or tests if there is not a consistent representation of the data in a form that enables past records to be digitally searched and compared.

4.3 Delay costs

Avoidance and mitigation costs impact the scheduling of research, development, operations and the introduction of new materials and products. The key to estimating delay costs is determining where the bottlenecks are, and which data exchange activities are time-critical, and which are not.

4.4 Opportunity costs

Opportunity costs arise when the lack of interoperability or inadequate or incomplete legacy data mean that the opportunity to develop new methods or new products cannot be achieved. There will be new benefits from increased accuracy and precision of the data and from increasing the quantity and the quality of data that is available for use.

5.0 ISO 10303 Product data representation and exchange

ISO 10303 is the original standard developed by ISO/TC 184/SC4 for the representation of engineering product data and provides the foundations for the technology of all product data representation in SC4. The historical structure of ISO 10303 is illustrated in Figure 2.

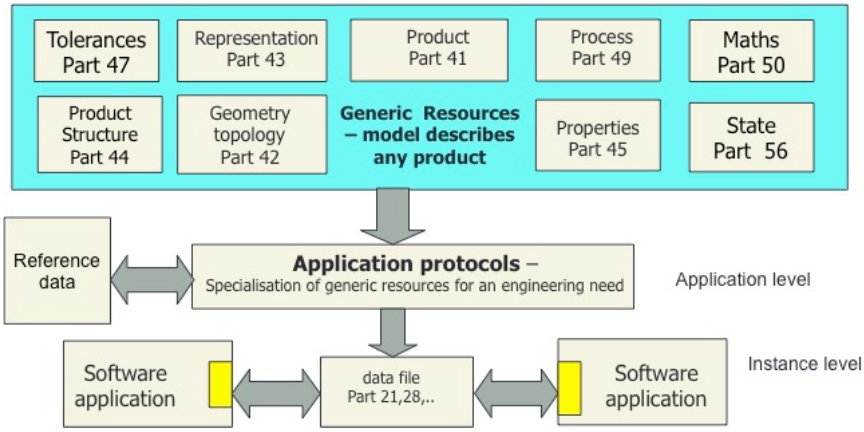

Figure 2. Illustration of the historical structure of ISO 10303 Product data representation and exchange

The principal feature of this structure is the single generic model that is the core resource from which all applications of ISO 10303 are developed. The generic model was separated into parts for ease of development, but each part was rigorously integrated into the whole generic model with no repetition or ambiguity between the parts. Part 45 had the original title ‘Materials’ and the first edition of this core part of the generic model was published in 1995.

Application Protocols are the sections of the ISO 10303 standard that are implemented in software or into software interfaces and have ISO 10303-part numbers starting from 200, e.g. 10303-242. The identification of an Application Protocol is usually shortened to AP followed by the part number, e.g. AP242. A list of some currently active APs is given in Appendix A. The collection of standards and the technology are also known colloquially as STEP - Standards for the Exchange of Product data.

ISO 10303 and the other standards developed by ISO/TC 184/SC4 (SC4 standards) use supporting technology as follows:

- The EXPRESS language, ISO 10303-11 – an object-oriented computer language for the representation of engineering information
- EXPRESS-G – a graphical version of EXPRESS to show the structure of a model as a diagram
- Data file formats that retain the structure of a model –
    - ISO 10303-21 Plain text presentation
    - ISO 10303-26 HDF5 Binary presentation
    - ISO 10303-28 XML presentation
- Bindings between EXPRESS and computer processing languages – C, C^{++}, Java.
- Standardised data access interface (SDAI) to guide interface development
- Directives for the presentation of documents to supplement the ISO Directives
- A quality manual to support quality control and quality assurance of the standards

The development of ISO 10303 and other SC4 standards therefore follows rigorous engineering practices for quality management. ISO/TC 184/SC won the Lawrence D Eicher Award in 2007 from ISO in recognition of the quality and rigour of its management of the standards for which it is responsible. Further information on ISO/TC 184/SC4 can be found on the Committee website: https://committee.iso.org/home/tc184sc4 .

6.0 Materials information in ISO 10303

6.1 ISO 10303-45 Materials and other engineering properties

The development of the representation of materials information within ISO 10303 standards has been dominated by the UK, with important contributions from the USA and Italy. The first edition of ISO 10303-45 Materials (Part 45) is a part of the Generic Core Model and was overseen by a sub-group of the BSI AMT/4 committee, meeting at the Institute of Materials with their support. Ferroday Ltd were the authors of the first edition of Part 45, published in 1995, and edited the subsequent versions.

The key concept of Part 45 is that all engineering materials are products, manufactured by a process, and therefore can be represented by the same digital representation technology as used for any other engineered product. The insight from materials knowledge is that the value of an engineering property is dependent on the collection of conditions in which it was measured – identified in Part 45 as the data environment. Part 45 therefore defines a material property of a product as a type of property whose value depends on the data environment. Part 45 provides resources to qualify the value by the representation of the uncertainty and reliability of the measure. The model also has the resources to represent the chemical composition of the product and its structure.

The first edition could only represent point values for properties but following the subsequent development of the mathematical resources in the core model - ISO 10303-50, the second edition provided the resources to represent a property value as a mathematical function with related uncertainty, such as is used for fatigue behaviour as an example. The mathematical resources also the include the representation of tables, matrices and tensors. Further editions of Part 45 have extended the dependent environment to include the dimensions of the product.

The representation of an engineering property as defined in Part 45 has been adopted in several Application Protocols.

6.2 ISO 10303-235 Engineering properties and materials information

ISO 10303-235 (AP235) is an Application Protocol that extends the concepts of ISO 10303-45 to represent the processes by which a property value is determined. AP235 includes all of the resources from the core model ISO 10303-49 Process structure and properties (Part 49). A visualisation of the concept of a process derived from Part 49 is show in Figure 3.

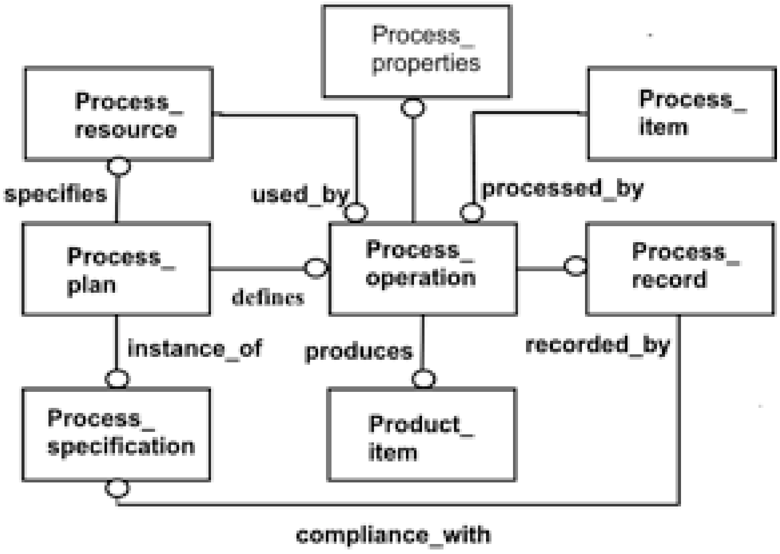

Figure 3 Information model for a process

The main items in the scope of AP235 are summarised in Table 1. Note that it is not necessary to use all of the scope in a software implementation of the standard.

Technical	Administrative
Product, product history and test pieces	Dates, times, persons, organizations, addresses
Properties of products and processes	Approvals, qualifications, certifications
Product substance composition and structure	Documents and files

Processes for all stages of measurement	External references
Process resources	Effectivity
Numerical and descriptive values	Languages
Mathematical expression values	Locations
Uncertainty and reliability of all values	Requirements
Dimensional and positional tolerances	

Table 1 Summary of the main features of the scope of ISO 10303-235

The achievement of AP235 is to connect together a product, a process and the properties that are the result of the process in a computer-processable information model. This connection is illustrated in Figure 4. Ferroday Ltd were the authors of the first edition, published in 2009, and of the second edition published in 2019.

The application of AP235 to a variety of testing and measurement processes has demonstrated the effectiveness of the AP235 model. Some of these applications are briefly described on the AP235 website (www.ap235.org) and are reported in more detail in the relevant publications listed in the bibliography. The AP235 information model has been implemented by the TenDEX ® software developed by Ferroday Ltd. Note that the representation of a process illustrated in Figure 3 can be used for any process and is not limited to a measurement process. The potential for the application of AP235 to a manufacturing process in the materials sector would be a subject for further research.

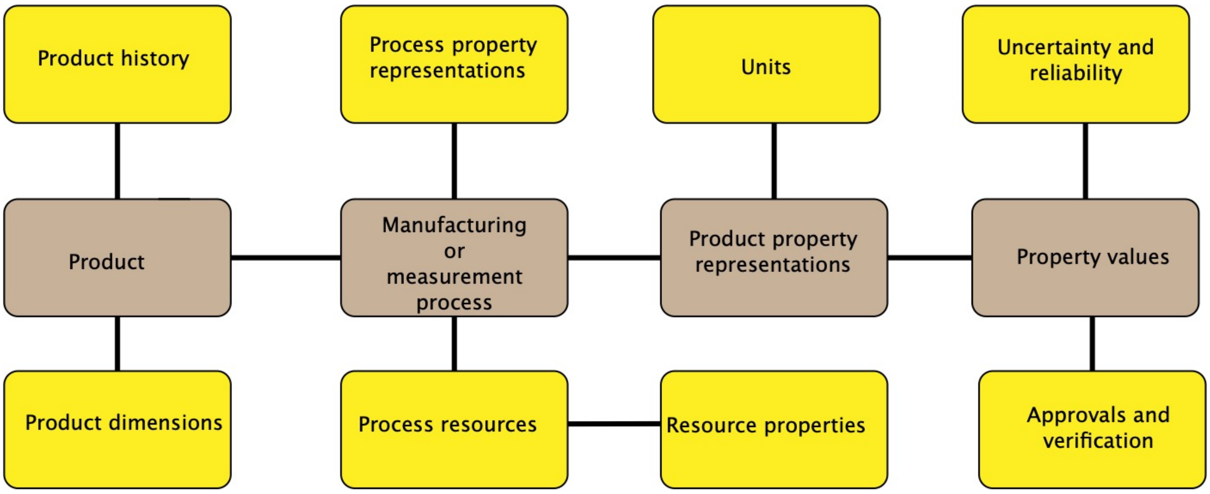

Figure 4 Overview of ISO 10303-235 Engineering properties and materials information

6.3 ISO 10303-209 Multiplicity analysis and design

The problem of the integration of information between shape design, structure, analysis and manufacture is made more difficult when the product is made from a composite material structure. ISO 10303-209 Multidisciplinary analysis and design (AP209) is the second edition of the standard that has developed a solution to this problem.

The interconnections between design, analysis and manufacturing information for composite material products is illustrated in Figure 5

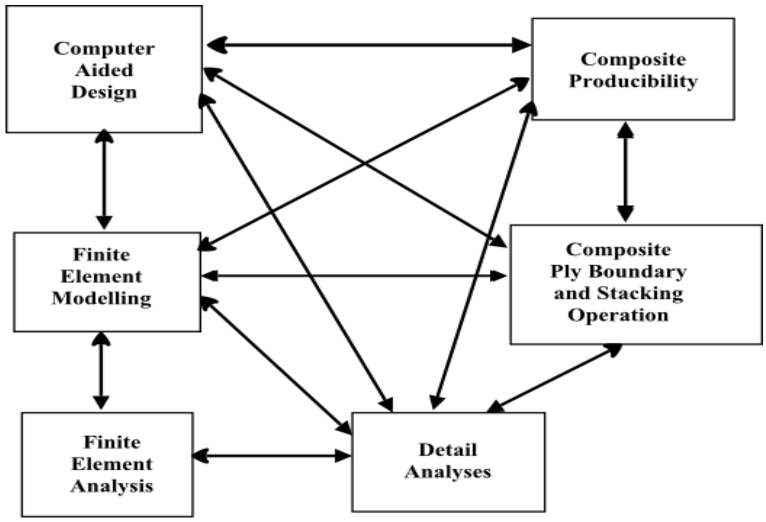

Figure 5 Interconnections between design, analysis and manufacturing information for composite material products

The information model of Edition 1 of AP209 provided resources to describe the following main concepts:

Finite element data: This includes models, analysis definitions and load cases, and results. A model can be specified in as much detail as required - if necessary, down to the level of element shape functions, discretisation points and integration rules. Static and natural frequency analyses are within the initial scope.

Configuration management data: A version of the finite element model is linked to a version of the product. This ensures that the correct finite element data may be associated with the correct version of a product within a Product Data Management system.

Product geometry: Both the design geometry and the idealised geometry created for analysis can be recorded. Nodes, finite elements, their edges, faces and volumes can be explicitly associated with aspects of the product geometry. It is possible to specify element properties, loadings or boundary conditions on a curve, edge, surface, or volume of the geometric model.

Composite lay-up: The lay-up of a composite part can be specified in detail. Shape, stacking sequence, and property information can be supplied about individual plies and their fibre orientations.

There are several types of laminate tables in ISO 10303-209 that vary from simple single ply laminates to sheet and volumetric assemblies. The assembly structures are non-recursive, though instances of items such as plies may occur more than once. Each of the constituents of a structure may be a product that has its own specifications and properties. These composite constituents may be made from several types of stock material. The constituent's shape may be specified either from a single mold surface or between two mold surfaces. The shape may be as simple as a 2-D sheet (either simple boundaries or topologically closed boundaries) up to a full 3-D solid. The orientation of the material in the plies in the laminate tables may be specified as a simple direction/rosette up to a continuously varying set of directions as is done in fibre placement, or a set of angles specified by a draping analysis. The shape of the constituent plies may be defined in a number of ways varying from simple lay-ups on a single surface to a choice of various projections.

The second Edition of ISO 10303-209 (AP209 ed2) – now renamed Multidisciplinary analysis and design, has integrated a generic Engineering Analysis capability complimented by specific Computational Fluid Dynamics (CFD) and a generalized mesh based numerical analysis capabilities to the AP209 Edition 1 classical Finite Element Analysis capabilities. The AP209 ed2 CFD capability is based upon the NASA/AIAA Computational Grid Neutral System (CGNS) standard and the Volvo Aero Engineering Analysis Results (EAR)-model work. The generalized structured and unstructured analysis and mesh capabilities in AP209 ed2 are based upon work done in the Generic Engineering Analysis Model (GEM) project from the European Union. In addition, there is a complete discrete/continuous mathematical field representation capability that has been added to AP209 ed2 based upon the David Talyor Labs/Boeing DT-NURBS package. All of these added capabilities have been integrated with the ISO 10303 common resources Parts 10303-50 (Mathematical constructs), 10303-51 (Mathematical description), 10303-52 (Mesh based topology), 10303-53 (Numerical analysis), 10303-107 (Finite element definition relationships), and 10303-110 (Mesh based computational fluid dynamics) as a basis for use in Application Protocols. The intent is that AP209 ed2 will now address a much wider set of multi-disciplinary analysis and optimization problems. A high-level overview of AP209 ed 2 is shown in Figure 6, below.

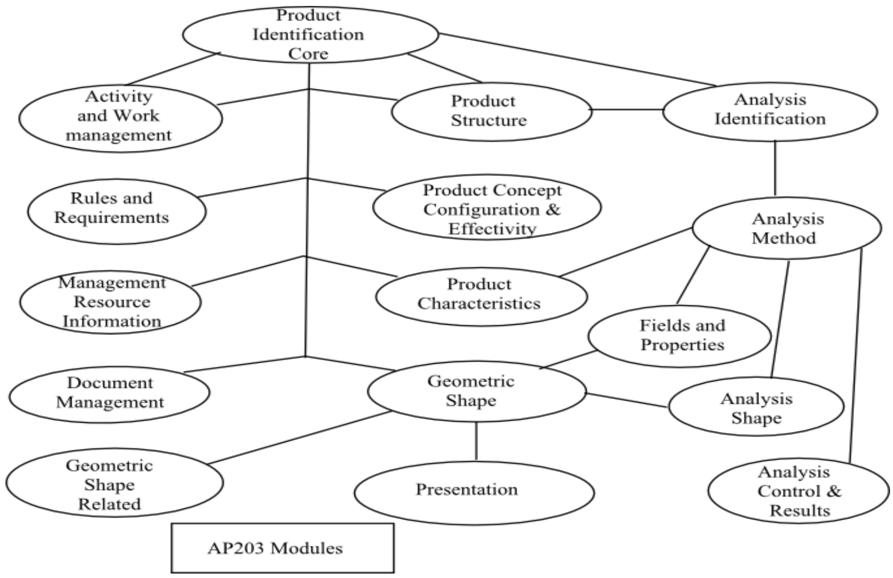

Figure 6 High level overview of ISO 10303-209 Ed 2

6.4 ISO 13584 Dictionary of test methods and properties

Section 2.2, above, emphasised that a complete digital representation needs a dictionary to define the meaning and format of the names and meanings of the data items in an instance of an information model. Dictionaries for applications of STEP standards can be developed by using ISO 13584. ISO 13584: Parts libraries (known as PLIB) was conceived as a standard for the representation of classifications of collections of products. PLIB uses an information model, defined in EXPRESS, which is specified in ISO 13584-42 and is common with the information model specified in IEC 61360. The most important consequence of using a standardized information model for the dictionary is that other classifications that conform to the same model can be combined. So, concepts and items that are shared between two knowledge domains need only to be defined once in one dictionary and then can be referenced from the classification in the other domain. The capability to reference one classification from a classification in another dictionary conforming to ISO 13584-42 was used successfully in ISO 13399: Cutting tool data representation and exchange (Nordström and Swindells, 2007).

The information model for ISO 13584 defines a classification of objects that is organised on the basis of their properties. Items in the classification can be super-classes of objects that have some properties in common and the association with the common properties is defined at the level of the super-class. Objects can be classified as sub-parts (feature classes) of other objects in order to be able to specify the properties of the feature. For example, a thread is a feature of a bolt and the thread has its own set of properties which are independent of the other properties (length, diameter, head shape, etc) of the bolt. However, a thread cannot exist in isolation from a bolt.

Because the model for the classification defines the names and definitions of types of objects and their properties, ISO 13584 can also play the role of a computer-understandable dictionary and this is the important aspect that is needed for ISO 10303-235. Protocols for accessing such a dictionary from information models specified in ISO 10303 have therefore been agreed and standardised and this capability has been incorporated in ISO 10303-235. In some models developed for ISO 10303, the names and definitions of the data items – the dictionary – are built into the models. The innovation in the use of ISO 13584 to provide the information model for a dictionary for ISO 10303-235 was to recognize that the types of objects in the classification could be measurement processes because types of properties are closely associated with the testing methods that simulate the behaviour which the property represents.

A dictionary of the names of testing methods and their properties therefore consists of a classification of measurement processes together with the properties that are associated with each class of method. Some methods e.g. uniaxial tensile testing, generate several properties from each application of the method. Each class of measurement method in the dictionary has: a name, a short name, a definition and up to three alias names. Each record of a process in the classification is identified with a unique identifier code, a version number and a revision number. The source of the definition can be identified together with the dates of the original record and any subsequent revisions. The identification code can be made unique, and a dictionary can have variants in different natural languages.

Properties can be defined as visible properties for the domain at the highest level of the classification and are then made applicable to the appropriate testing process. Each property has a name, a short name, a definition and a symbol. Up to three alias names and symbols can be specified. The units of the property value can be defined, and the property can be illustrated with a diagram. Each record of a property is identified with an identification code, a version number and a revision number. The source of the definition can be identified together with the dates of the original record and any subsequent revisions. A property may be dependent on another property and the dependence can be identified and can also be specified by a mathematical expression.

This concept of a dictionary of material testing methods and their properties using ISO 1358 4 was demonstrated (Kafka, 2003) by creating a prototype dictionary of some of the testing methods and their properties described in Military Handbook 5 (MIL-HDBK-5H) (U.S. Department of Defense, 1998). A screen shot of this dictionary, which shows the classification of a plane strain fracture test and one of its associated properties is shown in Figure 7. The dictionary was developed by using public domain software. The left-hand panel shows the classification of testing methods and operational conditions. The upper right-hand panel shows the definition of the selected testing method with a list of its applicable properties and the lower right-hand panel shows the definition of one of the properties associated with the method. ISO 10303-235 therefore uses a combination of: an entity relationship model to represent the complexities of the measurement of product properties and a classification model used as a dictionary to define and name the measurement processes and the properties that they generate.

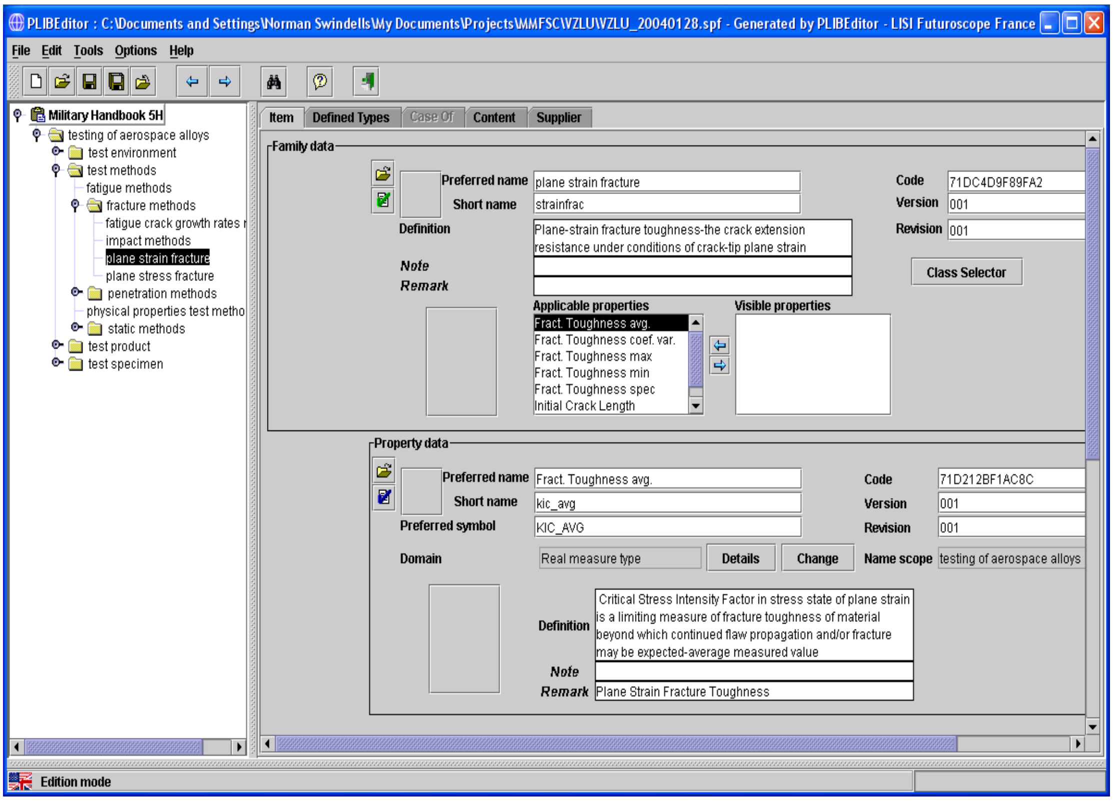

Figure 7 Screen shot of a portion of a dictionary of testing methods and their properties conforming to ISO 13584

7.0 ISO 8000 Quality of data

The concepts of quality assurance and quality control of information and data are the same concepts of quality assurance and control as for any engineered product: namely, conformance to a specification in a way that can be tested. These concepts have been documented in a series of standards in the ISO 8000 series developed by ISO/TC 184/SC4.

Information is defined by ISO 8000-8 as: knowledge concerning objects, such as facts, events, things, processes or ideas, including concepts, which has particular meaning within a certain context. Data is defined as: re-interpretable representation of information in a formalized manner suitable for communication, interpretation or processing. Metadata is data that describes and defines other data. A conceptual model is the model that describes concepts of a universe of discourse.

7.1 Syntactic quality

Syntactic quality is the degree to which data conforms to the specified syntax and domain dictionary. For example, a sentence in a natural language meets a requirement for measurable quality if it conforms to the grammatical rules of the language and uses words defined and spelt according to the relevant language dictionary. The product data standards that specify the syntax of digital engineering data represented by Application Protocols in the ISO 10303 series are:

- ISO 10303-21 – plain text representation of the exchange structure.
- ISO 10303-26 – binary representation of EXPRESS driven data.
- ISO 10303-28 – XML representations of EXPRESS schemas and data.

7.2 Semantic quality

Semantic quality is the degree to which data corresponds to the information that they represent. It is the unique and unambiguous correspondence with the external objects that the data represents. For example, a sentence has to be a true statement. The measurement of this quality requires a match to the requirements of the external objects in the real world as viewed through a conceptual model of this world. In product data technology the conceptual model is the information model for a given engineering requirement that is standardized in the appropriate Application Protocol.

The development of an Application Protocol proceeds through a series of formal modelling stages that are specified in the Supplementary Directives and conform to the requirements of a Quality Manual supervised by a Quality Committee. The three stages of model development are:

- Application Activity Model (AAM) – the information flows that have to be represented for a particular engineering situation;
- Application Reference Model (ARM) – defines the information objects needed to achieve the information flows defined in the AAM;
- Application Interpreted Model (AIM) – the normative part of the Application Protocol, written in EXPRESS, that specifies the resources from the generic product model in the Integrated Generic Resource that correspond to the information objects specified in the ARM.

The output of each stage is subject to international scrutiny and balloting to confirm whether it is an accurate representation of the real-world situation that the standard is intended to represent. The final stage of this development is a mapping process, which is formally described in the standard document, to demonstrate how the real-world concepts in the engineering requirement specified in the ARM have been represented in the AIM by the concepts described by the entities in the Integrated Generic Resource of ISO 10303.

Semantic quality is therefore an integral concept of ISO 10303 standards.

7.3 Pragmatic quality

Pragmatic quality is the degree to which the data is suitable and useful to those who use them. In other words, the data has to be understandable for the user. In applications of product data technology, the user will be the computer software system that is the receiver in a communication and exchange process. The requirements are therefore to know if the computer software application can use the data provided by the data file that it receives and, further, to evaluate whether a software implementation of the product data standard conforms to a complete and accurate image of the conceptual model in the standard.

The operation of the interface between the standard data file and a computer application is specified in ISO 10303-22 Standard data access interface (SDAI). Operations in the SDAI are defined that give the application programmer the capability to manipulate data through this interface based on its description in the defining information model. Computer applications are implemented using computer languages. The specification of the functionality defined in the SDAI in a particular computer language is described as an SDAI language binding. Since there are many computer languages, many SDAI bindings are possible. Four language bindings are currently standardized:

- ISO 10303-23 C++ language binding
- ISO 10303-24 C language binding
- ISO 10303-25 UML binding
- ISO 10303-27 Java language binding

7.4 Summary of quality assurance and control

ISO 8000 does not establish a new basis for a quality system but rather extends the existing ISO Standard 9001 for the management of quality for the case where data are the products that are under quality control. ISO 10303 extends this concept further by providing specifications for the representation of this data that supports its accurate communication and exchange. The developments of the standards produced by ISO TC184/SC4 were initiated by engineers in order to meet critical engineering requirements and the concepts of engineering quality control and quality assurance were built into these procedures from the beginning. Quality assurance is not something that can be added on later. ISO 8000 is therefore a consolidation of over thirty years of experience in the creation of engineered products that happen to be in the form of International Standards for the representation of engineering data.

8.0 Archiving

The previous sections have concentrated on the communication of information between different systems in real or close to real time. However, there is also the need to communicate with unknown systems in the future and that needs consideration of archiving product, process and measurement data in a form that is still digitally understandable and processable in the future. The adoption of a rigorous management of archiving avoids the problem of legacy data created in computer systems that are no longer available.

The Open Archiving Information System (OAIS Framework) was established by NASA for the archiving of satellite and other space data and has been adopted by ISO and standardised as ISO 14721. The OAIS Framework has six stages and there are important roles for SC4 standards in two of these stages:

- Ingest – inputting data records with metadata to enable them to be found in the future
- Data management – quality control and quality assurance of the input
    - Specifications for the data representations such as SC4 standards can provide the basis for QC and QA
- Storage – physical storage of data including back-up and migration to new media where necessary
- Preservation planning – ensuring that the data is not just a stream of unreadable digital bits when future access is required, and the original software systems are no longer available
    - S4 standards conserve the semantics as well as the syntax of the data representation independently from proprietary software
- Access – finding records in the archive and distributing them to appropriate users
- Administration – operation and maintenance of the archive

9.0 The current state of STEP technology

It would not be correct to assume that the work of ISO/TC 184/SC4 is concerned with the standardisation of already established concepts. The work needed to establish the technology and develop the standards could be more properly identified as original and fundamental research carried out on a global scale, subject to the constraints of the ISO standardisation rules and procedures. The current scale of the research and development effort has reduced from the original efforts that established the technology, but continual research and development is still required to develop either new versions or new standards to match the changes in industrial requirements and advances in digital representations and computer technology. Some of the latest developments are summarised in the following sub-sections.

9.1 Original document architecture

The fundamental basis of the architecture of a STEP standard document is illustrated in Figure 8. It has three levels of models. An Application Activity Model (AAM) describes the outline of the business requirement that the Standard is intended to answer. The first models described this business requirement in a formal model using the diagrammatic modelling language IDEF0. The other models in the architecture use the EXPRESS language and illustrate the models by using EXPRESS-G, the graphical version of EXPRESS.

The Application Reference Model (ARM) in the information layer is a model that describes the information requirements and constraints that are needed to satisfy the requirements specified in the AAM. This model uses terms and concepts that would be recognised by an industrial expert in the domain of the application. The Application Interpreted Model (AIM) is a representation of the items in the ARM achieved by a mapping process that identifies the common resources from the generic core model that correspond to the information items described in the ARM. The results of the mapping and any other additional required items are summarised in a short form list. A computer program is used to expand the short form into the complete long form of the AIM for the implementation of the Application Protocol. The ARM and the AIM are also illustrated with diagrams by using EXPRESS-G. the graphical form of EXPRESS.

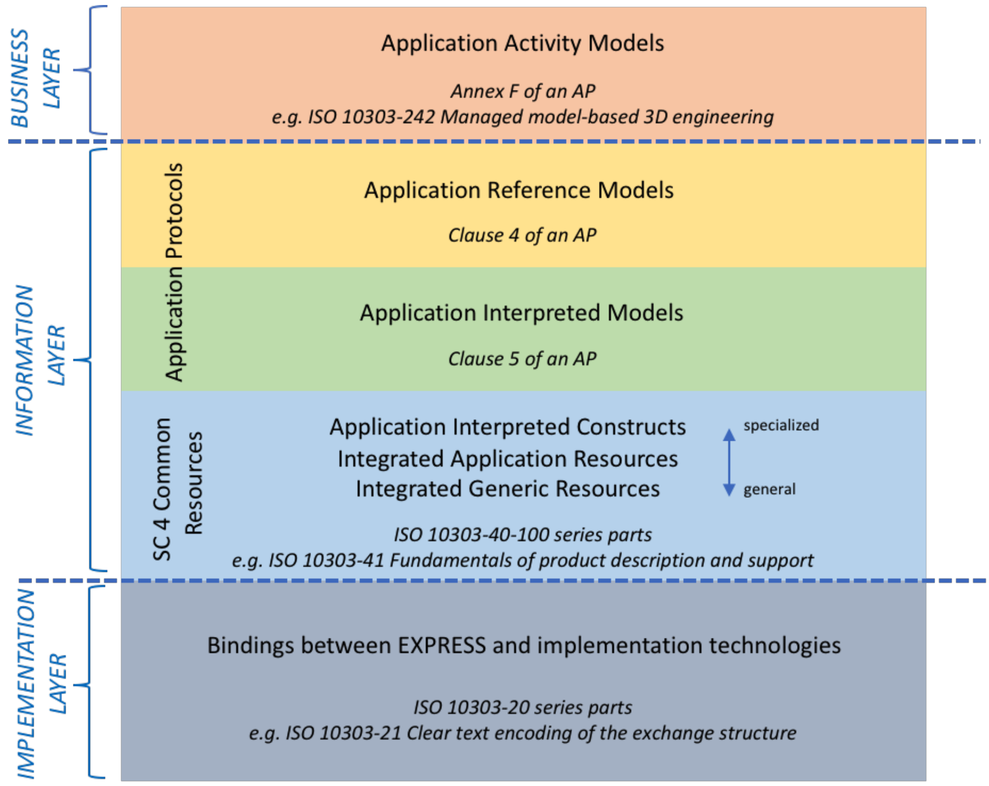

Figure 8. The fundamental architecture of a STEP standard document

ISO 10303-235 conforms to this document architecture, identified as ‘traditional’ or ‘monolithic’.

9.2 Modular architecture

It was recognised that the traditional architecture produces a document that is very large and that many concepts are repeated in different Application Protocols leading to overlaps that may not be completely harmonised. Some harmonisations in the geometric area were achieved with Application Interpreted Constructs (AIC – 500 series) which are smaller, reusable AIM models for aspects of geometry and topology. The break down into smaller reusable models was continued with the development of the modular architecture (400 and 1000 series). A comparison between the traditional and modular versions is illustrated in Figure 9. New editions on a modular basis of the previous monolithic APs have been developed (AP 203, AP 209, AP 210). The publication of these new editions coincided with the release in 2010 of a new ISO product: the STEP Module and Resource Library (SMRL). The SMRL contains all the STEP resource parts, application modules and Application Protocol AIM models on a single CD. This modular approach enables individual modules to be revised or extended without having to issue a new version of a complete AP document. Ferroday Ltd were not able to develop the second edition of AP235 as a modular AP because the revision required some concepts for which there no existing modules and the work required to create new modules and to recast the Standard in the modular architecture needed more work and resources than were available. However, the AIM of the second edition of AP235 was developed by mapping from the ARM to the latest version of the SMRL.

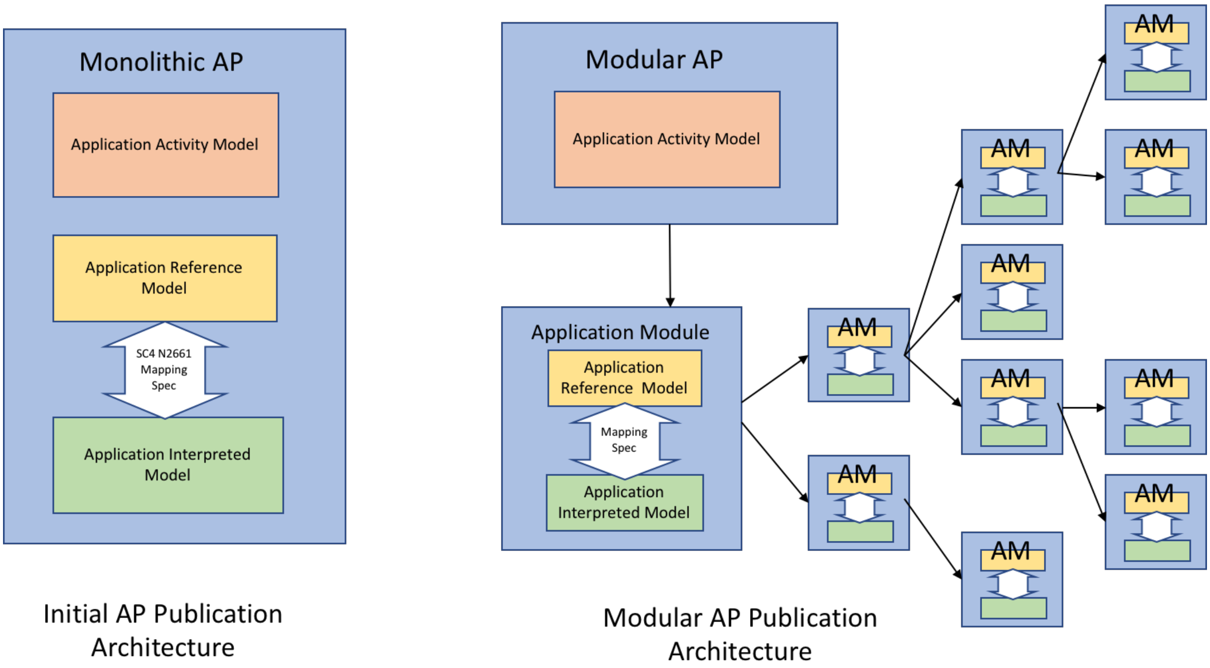

Figure 9 Comparison between the monolithic and modular architecture of a STEP standard document

A view of the current state of the active APs is summarised in the diagram in Figure 10

The title of AP 235 in Figure 10 was the title for the first edition of the standard. AP 242 is the common data backbone for CAD for both aerospace and auto and the agreement to have a common backbone is a testament to the confidence that each of these sectors have in the technology. AP242 replaces the previous standards AP203, used by the aerospace sector, and AP214 used by the German auto industry. The enhancements to AP242 include composites, kinematics, product manufacturing information and shape data quality. AP233 was originally developed by NASA. AP239 is for the management of product data throughout the life cycle after design and manufacture. AP239 is not typical of the other APs because it stops the modelling sequence at the ARM level.

So, the current state of STEP is that there are different types of APs in active use and development – modular APs (209, 242, 210), non-modular APs (235,238) and an ARM implementation (AP239). Although each of these has a large number of concepts in common, they may not always be modelled *exactly* the same, which would be needed for full interoperability. So, some of the current research effort is the development of a method to achieve full interoperability between all of the standards in this diagram.

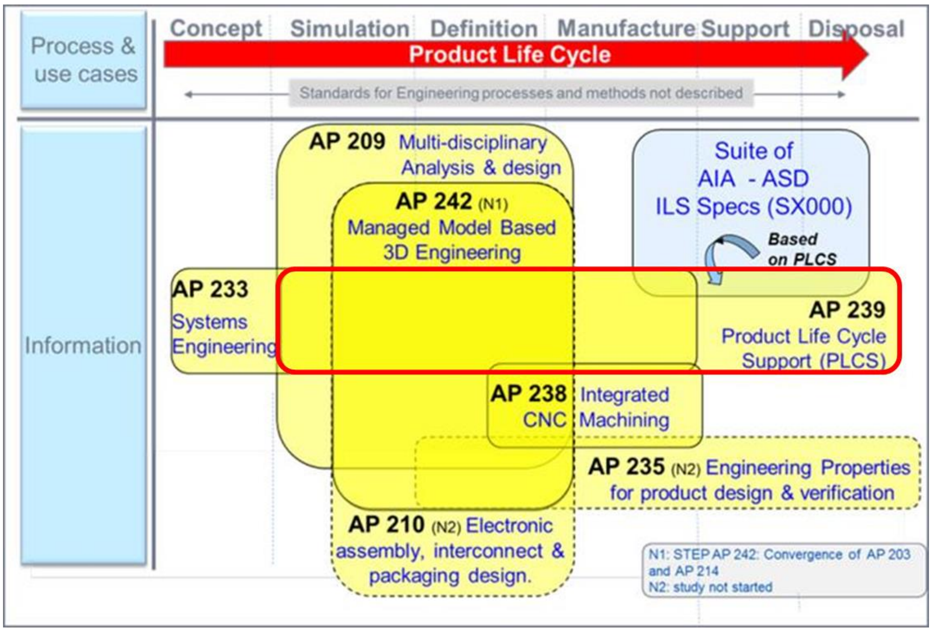

Figure 10 Overlap between some current STEP standards

9.3 Extended architecture

The primary requirements for an extended architecture for STEP are summarised in Figure 11. The important objectives are to enable STEP standards to be better integrated and to make more use of the resources available from the technology of the World Wide Web while not moving away from the three-level architecture describe in section 4.1 above. The current proposals for the extended architecture are illustrated in Figure 12.

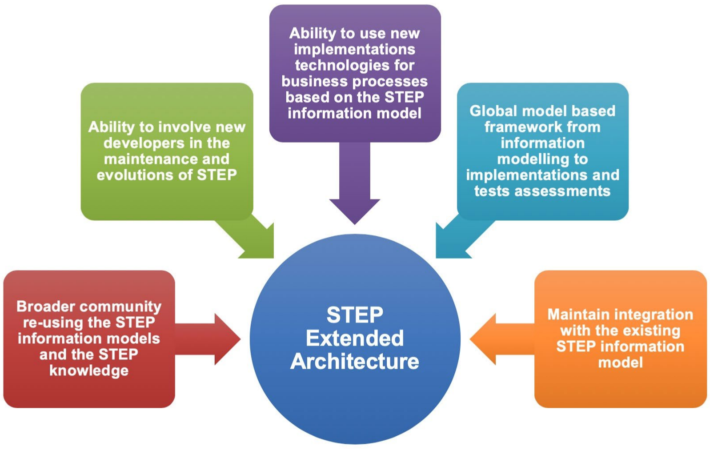

Figure 11 Primary requirements for a new architecture for STEP

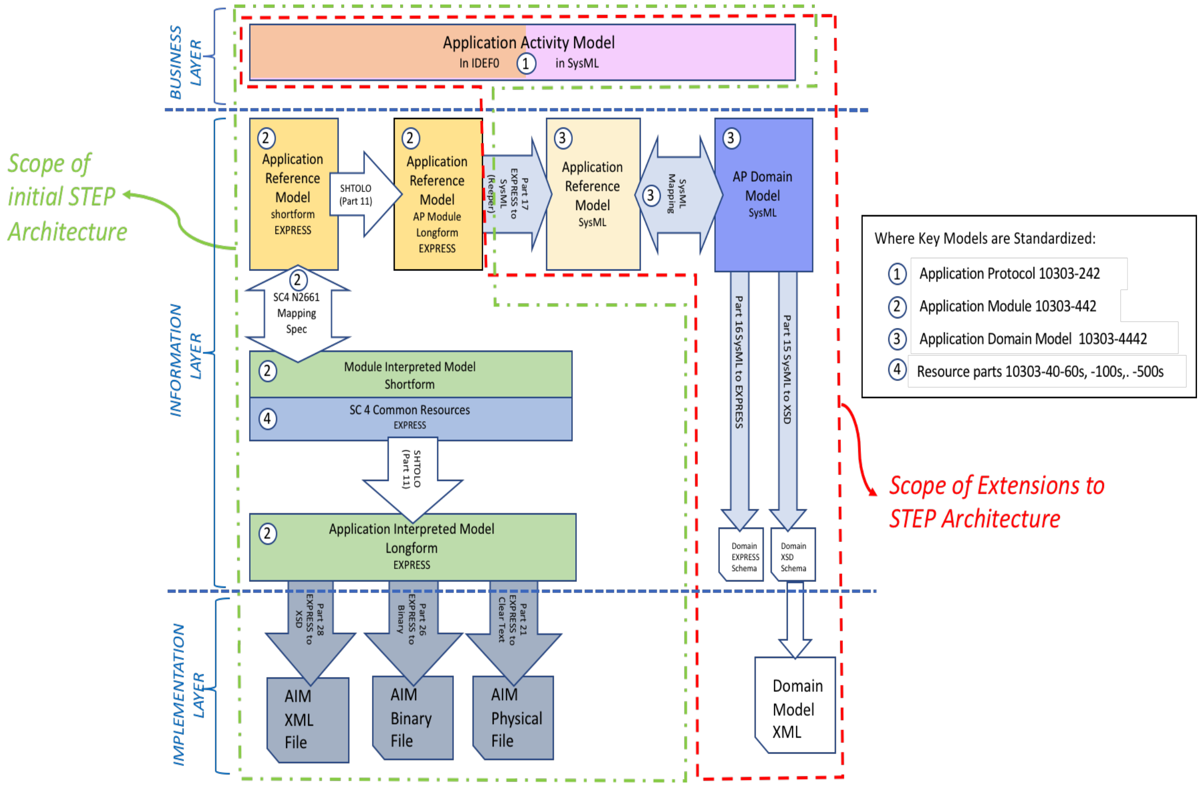

Figure 12 Illustration of the proposed extended architecture of STEP APs

To support the interoperability of AP242, 235 and 209 a new version of a core model ISO 10303-4000 has been developed and is currently being voted on.

The implementation methods for the extended architecture are summarised in Table 2.

Information model	**Modelling language**	**Implementation schema**	**Schema language for implementation**	**Data format for implementation**
Application domain model	SysML	Domain model XSD Domain model EXPRESS	XML schema Part 28 XSD	XML XML
ARM	EXPRESS	None		
AIM	EXPRESS	AIM long form	Part 11 EXPRESS Part 28 XSD Part 26 HDF5	Part 21 ed3 Part 28 Part 26
Business object model (BO model)	EXPRESS	BO model XSD	Part 28m XSD	XML

Table 2 Implementation methods for the extended architecture

9.4 Implications of the extended architecture

The early stages of the development of the SC4 technology were characterised by each major sector believing that they had a collection of requirements and an identity that were sufficiently different from others that there was a justification to develop an Application Protocol (AP) for their sector. One result was a multiplicity of APs which were not initially developed specifically to be interoperable, although they all used concepts from the generic core model. Experience since then has shown that there is more of a requirement for interoperability between the APs within the whole product life cycle. The importance of the change to the Extended Architecture is that this interoperability should be easier to develop and to achieve, although this has still to be demonstrated.

The current strategy is to try to reduce the number of APs and to include more capability with each one. The development of AP 242 as an agreed replacement for separate APs for the auto and aerospace sectors and the new version of AP209 are examples of this strategy. This strategy has implications for the materials sector. It would be very advantageous for the materials sector to have their interests influencing the development of subsequent versions of AP242 and AP239 so that the design and product life stages of the cycle took account of the information content and role of the material that the materials sector decided should be included in these Protocols.

9.5 Current status of ISO 10303-235

Notwithstanding the importance of the strategy for the Extended Architecture described in the previous two sections, ISO 10303-235 is currently the most complete digital representation of information that is relevant to several types of operations and applications in the materials sector. It could provide a starting point for exploring methods for the digitisation of the materials sector that Materials 4.0 describes. If Materials 4.0 can demonstrate the value of this AP and the materials sector can find a way to approve its general use, then there will be a great less work needed to achieve this adoption than would be the case if Materials 4.0 started a new method from scratch. There will also be a stronger case and more experience available in order to influence the further development of SC4 standards if needed to meet the requirements of the materials sector.

9.6 TenDEX® software

The user interface of a software application that implements a STEP Standard for the representation of 3-D CAD enables the manipulation of the entries in a data base to select appropriate data items to create a 3-D image. The CAD software then outputs the result as data file conforming to ISO 10303-21 (Part 21 file). The TenDEX® software developed by Ferroday Ltd carries out the equivalent operations on items in a data base that implements the ISO 10303-235 Standard to represent the properties of products and processes. The software is a web application accessible with a browser. The user interface enables the selection of entities from a drop-down list to be selected for use in a particular application and the attributes that need a value to be input are displayed. A full data representation can therefore be built up quite quickly. If there is a requirement to repeat the input of values for the same properties, then a collection of templates of properties can be created and compiled into a form for the input of the values for a complete test, for example. So, a form for a uni-axial tensile test of a fibre reinforced composite coupon could include fields for the input of set of values for crosshead speed, temperature, humidity, rupture stress, maximum force, rupture elongation, Poisson coefficient.

10.0 Objections to the use of ISO 10303 standards

The materials sector has been reluctant or otherwise opposed to the use of SC4 standards and some of the objections and potential answers to these objections are summarised in this section. They are divided between their relevance to the strategic and technical streams of the Road Map described in the following part of this report. Potential replies to the objections are described in the paragraphs following the objections.

10.1 Strategic objections

Resistance to proposals for a strategy for the adoption of SC4 standards from the materials sector companies in the past have included a response in the form of: 'we only respond to what our customers urgently demand and then we might consider it'.

All of the OEM level companies that use SC4 technology have adopted it for their own benefits in order to reduce their own costs and increase their own efficiency and profitability. In making this change they then found that their customers also benefited. Managing the technical information in a business should be given the same attention as the management of the finance. Both have value and are essential for the wellbeing of the enterprise and its future. So, a strategic decision to adopt SC4 technology depends on the financial costs and benefits for the adopter and on the relationships with their customers, some of whom will have also adopted this technology. In the aerospace sector, Airbus requires end-to-end overall optimum interoperability, dedicative views, capability for the re-use of information and collaboration across functions within their supply chain and with their customers. The Association of Aerospace and Defence Industries in Europe has identified a backbone of standards to enable cross-domain interoperability in the aerospace and defence product life cycle (www.asd-ssg.org/through-lifecycle-interoperability) in order to improve profitability for the European sector.

10.2 Technical objections

Opposition to the use of SC4 standards from technical experts have included comments such as:
STEP is too complicated and too big and there must be a simpler, easier solution.
We don't want a general solution for every material we want a solution for our material to be competitive against rival materials.
International standards are too vague and too general to be of any use in specific cases.
We are satisfied with the commercial data base that we already use.
The Building Information Model will meet all of our needs.
We have no one in the company who could understand what you are proposing.

The digital engineering of the range of information for the materials sector and its processes is a complex problem. Complex problems cannot usually be solved by a combination of simple solutions and it is better to deal with the complexity in its own right. The answer to this particular objection was to select an appropriate level of abstraction able to model the data for the materials domain but one that can still include enough detail to be technically relevant. The particular level of abstraction that has been shown to successful in this case was model a 'material' as a product, since all engineering materials are produced by a process. The result of this choice was that the resources for the digital representation of product information were already available in the core model of ISO 10303 and hardly any new concepts had to be developed. The strongest answer to this objection is that a STEP standard is implemented in software and it is designed for this purpose. Its use is therefore invisible to the user of the software and the only place where it can be observed is in the format of the output file.

The answer to the second objection is that that the main users of materials do not use only the output from one sector and require a solution that can be applicable to every type of material.

An International Standard is not mandatory but can be one of several types. Some describe frameworks that provide general advice or procedure, but most are specific. So, if an International Standard is adopted for the description of a product then the requirements specified in the Standard *shall* be followed. SC4 standards are in this latter category.

SC4 standards do not replace data bases, although they have advantages for long-term archiving. They provide an additional capability to be able to follow a product throughout its life cycle and are able to add information throughout this life in a dynamic process.

The Building Information Model (BIM) is similar to an Application Protocol in its purpose, but the scope and its details are directed at the requirements of the construction and infrastructure sectors. It uses the equivalent of modules (IFCs) to model detailed parts of the structure of the model, the language used for the model is EXPRESS and it uses the geometry and topology model from ISO 10303-42 for the representation of 3D components. Material product suppliers could use the BIM to provide relevant product information to their customers in construction and infrastructure, but it has limitations as a model for the materials sector itself. Apart from the 3-D geometry component, it is not compatible with any of the SC4 standards because it is not based on the STEP Core Model and so it is not relevant for the supply of information to the aerospace and auto sectors. The BIM does not have resources for the representation of manufacturing processes, it does not have the means to represent the testing of products and has limited or no capabilities for product manufacturing information, composition and structure. The BIM does not have any resources to represent mathematical expressions. ISO 10303-235 has been specifically developed for the materials domain and so there should be no justification for using a model intended for another domain.

The main problem with the objections from both the strategic and technical streams is the lack of education and understanding of what SC4 technology has achieved and the proposals for meeting the requirements for this aspect are discussed in the next section and are dealt with in the Road Map sections of this report.

10.3 Diffusion of the technology and the mitigation of objections

The mitigation and management of objections from the materials sectors to SC4 technology and its application will require actions to understand the nature of their problems and the harnessing of strategies and resources specifically to overcome any reluctance to adopt the technology.

The first requirement will be to have materials sector technical experts involved in the S4 technology and its application, as is the case with all of the other sectors that have adopted SC4 standards. It is not enough for the materials domain to rely on the solutions to the engineering requirements of other sectors. There should also be trust in the results of the enormous effort that has been put into the creation of the standards and their continuing development.

The diffusion of a new technology has five features that could be relevant to a strategy for overcoming objections to the adoption of SC4 technology in the materials sector and that will influence the directions and milestones in the Road Map. These features are described in the book ‘Diffusion of Innovations’ by Everett Rogers. They were summarised in a recent post by the Made Smarter section of the Knowledge Transfer Network (KTN) and these features are: *relative advantage, compatibility, complexity, trialability and observability.*

Relative advantage
For most technologies, an adopter wants a significant step forward in function or features. New ideas have to be tested with the right users in order to quantify the benefits. Game changing innovations therefore diffuse more quickly. There are several examples where the use of SC4 technology has provided significant advantages with reductions in time, cost and improvements in completeness, accuracy and precision.

Compatibility
Compatibility of SC4 APs with PLM or ERP systems has been shown in several public demonstrations and the same information representations are used in ISO 10303-235 as in these use cases. There is still some incompatibility between current APs and this is being addressed with the developments of the Extended Architecture.

Complexity
An Application Protocol is designed and developed in increasing stages of complexity. The first two stages, the AAM or Business Model and the ARM, use terms and concepts that are used in the sector that the AP addresses. They are relatively short and are fully described and illustrated in the standard document. So, the scope and meaning of an AP should be understandable by any professional engineer from these two stages alone. The AIM is derived from and mapped from the ARM in the form of a computer algorithm and this is specifically intended to be understood and used by a software engineer for integration or implementation in software.

Trialability
Where an AP is implemented in software, the vendors usually allow a free trial for a limited period. The TenDEX® software that is the first implementation of AP235 has on-line tutorials and step-by-step guidance for new users.

Observability
The early of stages of the adoption of product data technology were made observable because major companies adopted them for CAD: Boeing for ISO 10303-203 in aerospace and Daimler for ISO 10303-214 in auto. Airbus is now a major player in the adoption of AP239 and

in the development of new SC4 technology in the Extended Architecture. Later champions included Sandvik Coromant for ISO 13399 developed for machine cutting tools.

A major influence on observability of product data technology has been the establishment of national bodies to bring together companies and other organisations to share experience and promote the technology for both their own and the national benefit. In the USA this body is PDES Inc, in Germany it is ProSTEP, in France it is AFNET. In each case, these bodies are additional to the nations standards committee that mirror ISO/TC 184/SC4. The members of these national organisations are representatives of industrial companies who pay a membership fee for participation and for the benefits that they obtain. There is no such organisation in the UK at present, although there was a similar one for the bulk chemicals sector in the early years of the development that was called PISTEP. The UK government has recently been a major promoter of the Building Information Model and this promotion has been strongly supported by BSI but neither has recognised or promoted the benefits of the wider applications of product data technology to more industry sectors.

If Materials 4.0 is to be the main player in promoting product data technology for the materials sector in the UK, then there are several examples from which it could learn. Examples of activities from these national bodies include:

- A forum for technical discussions with feedback to the standards developers
- A forum for software implementors with feedback to the standards developers
- National conferences to show recent developments and applications
- A one-stop-shop for directing access to experts and information on product data technology
- Development of national strategies for input to the development of standards
- Advisors to government and other agencies on policy and funding
- Direction and management of funding for appropriate projects

11.0 Conclusions and research opportunities

The technology for product data technology developed in ISO/TC 184/SC4 has demonstrated its reliability and extensibility over 30 years. The technology continues to develop and expand due to the fundamental features built into the technology from the beginning. It would be a mistake to regard ISO Standards as fixed and immovable. The further development and the application of ISO 10303 standards in the materials sector should provide opportunities for research at TRL 1-3 and this would be consistent with the basis for the funding in Materials 4.0. The Standards from ISO/TC 184/SC4 were the result of fundamental research and this research is still continuing. There would therefore be opportunities to identify topics for new kinds of research as a result of more active involvement from the Materials 4.0 community in ISO/TC 184/SC4 or, as a minimum, in BSI AMT/4. There will be opportunities for materials scientists and engineers and for data scientists as a result of the demand for new materials and processes and from new developments in software engineering and digital technology.

If materials scientists, materials engineers and data scientists are going to specialise in data modelling and data representation for the materials sector then it would be necessary for the main materials journals to extend the scope of their publication topics to include this subject. One of the main reasons why the materials sector is unaware of this technology is that the main materials journals do not provide a venue for this type of research to be published and the panels of reviewers do not include anyone who could provide an opinion on the validity and veracity of the research. The achievements of the technology are mostly invisible to the materials sector at present because of this lack of exposure.

It should be remembered that this is an International technology and major companies are international in their reach. Consideration should be given to making connections with at least the European materials societies for the International dissemination of the digital technologies that Materials 4.0 investigates and develops.

An important aim should be to add weight to the importance of the materials content of SC4 standards in order to safeguard the interests of the material sector in this digital technology.

12.0 Road map

The proposed road map is intended to identify actions and resources to promote the adoption of SC4 standards on order to achieve the digital-centred objectives of Materials 4.0. The Road Map takes account of the current state and likely future developments in the SC4 standards and technology.

The sections of the materials sector to whom these recommendations could relate include:

- Primary producers and the supply chain of materials
- Secondary processers such as component manufacturers, forming and treatment operations
- Stockholders
- Independent testing houses and manufacturers of test pieces
- Catapult Centres
- Academic departments for materials
- Trade associations

The materials classes include metals, ceramics, plastics, composites, glass, paper and cement.

This range is large and diverse and a focus on a defined area is suggested as a starting point so that the lessons learned would be the basis for a wider diffusion to more sections and more materials. Since the main companies that are active in the development and deployment of advanced SC4 technology are in aerospace and defence, it is proposed that the starting point for the road map should be pointed in this direction first. Later, other sections would be approached with the confidence that had been achieved from the actions for aerospace and defence. One benefit of this approach is also that it avoids a confrontation with sections of the materials world that have so far expressed reluctance to adopt the SC4 technology.

An important feature of other sections of the SC4 technology is the value of a user group that brings together software implementers of the standards and users of the software to provide feedback to the developers of the technology and the standards. It is recommended that a User Group for materials applications of SC4 Standards should be formed and sponsored by Materials 4.0.

12.1 Starting point

It is proposed that a starting point for the road map could be the demonstration of the application of SC4 standards to the product life cycle of a fibre-reinforced composite component from the starting materials through the testing of the laminates to the design and testing of the finished component. Much of this sequence has already been successfully demonstrated, supported by Innovate UK in the competition 'Game changing technologies for aerospace.' This application would be a learning exercise for Materials 4.0. The application could involve several parts of the supply chain, possibly including testing machine companies, and be a demonstration of the benefits of the flexibility and generality of the technology.

A justification for this use case is that the original requirement for ISO 10303-235 was a business case from Boeing. They wanted an audit trail for the origins of the properties of a design of a part, particularly where that part had failed in service. They also wanted a digital trail that could be audited by the regulator for the approval of a component. This type of audit trail is also required in other industrial sectors, such as for nuclear power plant for example. Examples of the commitment of the aerospace and defence sector to SC4 standards are two recent statements from Jean-Pierre Souzy, of the Strategic Standards Group of the Aerospace and Defence Industries Association of Europe (ASD-SSG).

"The ASD-SSG supports the development of ISO STEP Core Model (ISO 10303-4000) as an integration layer between STEP Application Protocols, contributing to the ASD-SSG "Through Life Cycle vision". In its first version, this Core Model enables industry to move data between the STEP Application Protocols AP242, AP239 and AP243." (See section 9.5)

"The ASD-SSG supports the development of ISO 10303-243 (MoSSEC) for managing the Systems Engineering context data associated with Modelling and Simulation activities, contributing to the ASD SSG Through Life Cycle vision. In its first version, this STEP Application Protocol enables Industry to share collaborative Modelling and Simulation data across companies and platforms. "

Note that these are new developments and are not yet complete or proven.

Objectives and time scale

The deliverables for this starting point would be STEP data files for each of the stages in the product life cycle. The time scale for the completion of this starting point would be six months.

12.2 Road map streams

It is proposed that there could be four main streams for actions that would achieve the objectives of Materials 4.0: strategic, technical, modelling and software. Each of these main streams would need a common cross-cutting inter-connection of education and training. A road map also needs the identification of objective destinations and an estimate of the actions needed to reach the objectives in a way that can be measured.

It is proposed that the issues and the actions that the road map identifies are common to all sections and all types of operations within the materials sector. The lessons from the other industrial sectors that have adopted SC4 standards is that these issues are common across a sector and are therefore outside competitive advantage. So, there are great benefits from cooperation within a sector as a whole. It is therefore strongly recommended that the different streams should *not* be further segmented on the basis of materials class and that representatives of any materials class should play a role in a stream and in the identification of its actions.

In addition, it is recommended that at least the tactical and modelling streams should each have a representative in ISO TC184/SC4. For this to be achieved they would have to be registered as representatives of the UK by BSI. This would first require them to apply to become members of the BSI Committee AMT/4. Membership of ISO TC184/SC4 conveys considerable privileges and advantages. It enables privileged access to ISO documents and standards, the capability to influence future standards, membership of a global consortium of expert knowledge and experience and personal contact with senior engineers from OEMs. ISO TC184/SC4 currently meets in full session twice a year for six days at each event but working groups meet virtually, on-line, more frequently: weekly in some cases. In normal times, the meetings of ISO TC184/SC4 cycle between face-to-face meeting in Europe, USA and the Pacific Rim. BSI AMT/4 currently meets four times a year. Membership of BSI AMT/4 would also allow formal liaisons to be established between Materials 4.0 and the BSI Committees that relate to the materials sector and its products.

12.3 Strategic stream

The strategic stream covers the management actions and policy decisions that would be needed to adopt the SC4 standards for businesses and for research and development in the materials sector. The relevance and viability of the proposed strategic actions will depend on the size and capabilities of an organisation or enterprise. The aim should be to have at least three organisations related to the aerospace and defence sector as participants on this route.

Proposed strategic stream actions

Attend introductory webinar.

Evaluate the cost of legacy data that cannot be used because the software system needed to interpret it is no longer available, or the data is incomplete, or metadata are incomplete or missing, or the data format is incompatible with current systems.

Measure the costs of non-interoperability of digital communications of product data both internally and from external communications.

Consult the domain experts from the Technical stream to assess the feasibility and relevance of SC4 standards to the organisation.

Identify the costs of software and training to adopt SC4 standards to improve data management, interoperability and archiving and relate these costs to the potential benefits.

Decide whether to adopt the use of SC4 standards for the benefit of the organisation.

Establish a post of information manager, if one is not already in place, to support the effective management of technical data.

Purchase software to enable to use of SC4 standards relevant to the organisation and its customers.

If software is not available and resources permit, then commission the development of software to support the use of relevant SC4 standards.

Establish education and training to ensure that all relevant parts of the organisation are aware of the strategy and apply and use the strategy where relevant.

Support provision of new resources and funding to further the development and diffusion of the technology within the sector.

Objectives and time scale

The time scale for the main actions in the strategic stream would be 9 months.

The objective would be reports from each participant in the stream summarising the outcomes of the actions with proposals for any continuing actions and commitments.

12.4 Technical stream

The participants in the technical stream are the domain experts who create and use the technical information relevant to their organisation. The domain of technical experts participating in this stream would not have to be limited to the field of composites in the introductory demonstration.

Proposed technical stream actions

Attend introductory webinar.

Undergo education and training to become familiar with ISO practice and the SC4 technology relevant for their domain.

Identify which operations in their domain would benefit from the use of SC4 technology.

Identify what use any customers or suppliers make of SC4 standards.

Identify if any current systems are already enabled to input and output data conforming to a STEP standard and if so, then measure the potential savings and technical benefits that could be achieved by their use.

Identify where inadequate or inaccessible legacy data is causing problems with current activities.

Identify and evaluate software available for SC4 standards relevant for current and future operations.

Support the generation of funding and actions to develop software that meets the needs of the domain.

Identify inadequacies or new items that are needed in the SC4 models relevant to the domain and lobby for funding and domain participation for models to be extended or new models developed.

Participate in research and development to identify new uses and new applications of SC4 standards for the domain.

Objectives and time scale

The objectives of this stream would be reports on the applicability of SC4 standards to their organisation and domain. The time scale for the main actions in the stream would be 9 months.

12.5 Modelling stream

The participants in the modelling stream could be existing modelling experts in the STEP community, domain experts with modelling experience and data scientists who would represent the interests of the materials sector in the future development and implementation of the standards. The manpower needs for this stream would be small.

Proposed modelling stream actions

Attend introductory webinar.

Undergo education and training to become familiar with ISO practice and SC4 technology where necessary.

Become familiar with the SC4 models relevant to the domain and monitor related developments and updates.

Provide reports and feedbacks on issues and developments related to the modelling and development of SC4 standards.

Develop Best Practice Guides for the use of relevant models and promote their wide distribution and acceptance.

Investigate differences between the modelling of material information in different APs and develop better harmonisation between them.

Contribute effort and resources to further developments of SC4 standards relevant to the domain such as a third edition of ISO 10303-235.

Participate in research and development to identify new uses and new applications of SC4 standards.

Objectives and time scale

The first objective of this stream would be the development of Best Practice Guides to the use of SC4 standards relevant to the domain. This will need liaison with the Technical Stream and will be controlled to a large extent by the requirements that they identify and their time scale.

12.6 Implementation stream

The participants in the implementation stream would be software engineers who can develop new software and software interfaces to add the capability for the use of SC4 standards to the application systems in their organisation or their domain.

Proposed implementation stream actions

Attend introductory webinar.

Undergo education and training to become familiar with ISO practice and SC4 technology.

Review the details of the SC4 standards relevant to their domain.

Review the software tools already available for the implementation of SC4 standards.

Develop software and interfaces to enable the use of SC4 standards within the organisation and, or, the domain.

Participate in research and development to identify new uses and new applications of SC4 standards.

Objectives and time scale

To be decided.

12.7 Education and training

The general approach would be to structure the content of the events and courses to satisfy requirements for Continuous Professional Development (CPD) with the award of certificates for successful participation and completion. An application could be made to the Institute of Materials, Minerals and Mining to provide this service, subject to their approval of the content. Important objectives of the courses are to achieve feedback on the technical requirements of the domain and to increase participation from the domain in future developments and approvals of new standards. The progress of the programme will be dependent on the feedback from the early stages in order to ensure that future content meets the requirements of the participants.

An education and tutorial website should also be developed for a more permanent source of information for self-education with feedback. This site should be updated as new information and new courses become available.

Proposed education and training streams actions

Introduction webinar to product data technology and its potential for applications to the materials sector – half day, all materials sections, all streams.
Technical stream – detailed scope and applications of ISO 13030-235 – half day, all materials sections.
Technical stream – identification of current problems, requirements and potential solutions – a series of small time slots throughout the duration of the Materials 4.0 project as experience and information develops.
Modelling stream – sources and details of modelling resources – half day.
Implementation stream – sources for SC4 models and supporting software – half day.

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Annex A Titles of some current Application Protocols

ISO 10303-203 Representation of 3-D computer-aided design – the first standard to be implemented in every commercial 3-D CAD software application, should now be replaced by ISO 10303-242.

ISO 10303-242 Managed Model-based 3D Engineering – adopted as the common standard for CAD for the aerospace and auto sectors. (www.ap242.org)

ISO 10303-209 Multidisciplinary analysis and design – standard for composites design incorporating FEA and CFD data: developed and used by Lockheed Martin Aerospace. (www.ap209.org)

ISO 10303-233 Systems engineering – defines the scope of the information required during the stages of the design of a system: developed and implemented by NASA.

ISO 10303-235 Engineering properties and materials information – represents any engineering property of any product measured by any method: developed by Ferroday Ltd. (www.ap235.org).

ISO 10303-238 Application interpreted model for computerized numerical controllers – STEP-NC: one of a collection of standards to support smart manufacturing. (www.steptools.com)

ISO 10303-239 Product life cycle support – supports the maintenance or modification of any complex structure: used by Airbus, supported by MoD and NATO.

ISO 13584 Parts libraries – classification of collections of products and their properties for parts lists, etc.: supports the dictionaries for ISO 13399 and ISO 10303-235 and other applications.

ISO 13399 Cutting tool data representation and communication – detailed description of modern machine cutting tools and integrated with ISO 10303-238. (www.sandvik.coromant.com)

Long term archiving and retrieval of product data (LOTAR) – uses ISO 10303 standards in the OAIS archiving framework from NASA, standardised as ISO 14721. (www.lotar-international.org)

ISO 8000 Quality of information and data – engineering quality control and assurance based on testable conformance to a specification such as defined by an ISO 10303 standard.

Henry Royce Institute • Royce Hub Building
The University of Manchester • Oxford Road • Manchester • M13 9PL
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