An additive technology data framework

Part 1: Introducing a data model for energy industries.

White paper

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Baker Hughes

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An additive technology data framework

A data framework to enable additively manufactured products in an industrial marketplace environment for the heavily regulated energy industry.

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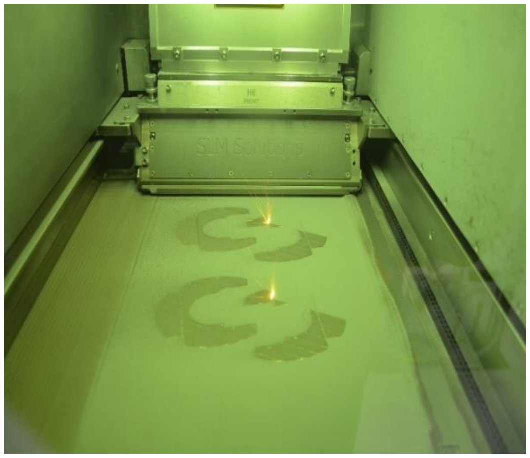
The use of additive technologies in the industrial product development and manufacturing operations has been steadily growing. However, the initial predictions of it transforming the supply chain operations remain unrealized. An idea to build a B2B additive marketplace to reduce physical inventory by managing digitized artifacts (data) required to repeatedly produce parts resonant within the industry, specifically among the Energy Operators. To realize the idea, the industry must solve significant challenges relate to the data security, quality, consistency, accuracy, completeness, etc. If resolved, the industry could really see benefits from reduction of non-productive time (NPT) due to parts failures and the cash held up in the physical inventory of operationally critical parts. The process to expand additive technologies into broader industrial product portfolio is often mired in long material & product qualification cycle, expanded post processing & increased quality controls. – making up for higher cost than the traditional manufacturing methods. Of recently, American Petroleum Institute (API) has published standards for qualifying additive parts. The standards: API 20S for metallics and API 20T for non-metallics, require an extensive set of data to be collected & reported throughout the entire product development and manufacturing lifecycle. To comply with the API standards, each additive product manufacturer needs to create a framework for data collection, reporting and archiving. Consequently, the end users of the additive parts also need a framework to validate the incoming data against their expectations and requirements.



The commercial software available to manage additive lifecycle processes are limited in scope, feature sets. and the underlying data model required to meet intensive data requirements from API standards. Additionally, they lack connectivity to the wider enterprise systems, where bulk of company's operations are performed, and much of the data needed for API standard compliance reside. A data framework is needed to realize the idea of B2B additive marketplace (thus create opportunities to realize additive business value)- with a consistent process for certifying parts as per the industry regulations. The common data framework could reduce the investments from each manufacturer (and the end user, as well) of the additive products to independently creating infrastructure to meet standards' requirements – and provide industry guidelines to additive software manufacturers.

In this series of papers, a data framework is proposed that could further the ongoing discussions within the industry on this topic, and if adapted by the industry, it could help industry realize its business aspirations while complying regulations.

Additive technology: an opportunity to improve product performance & supply chain operations.

Additive Technologies have been steadily becoming key components of product design and manufacturing methodologies across various industries. Additive Manufacturing offers opportunities to relook at the conventional supply chain with far reaching impacts such as reduction the number of suppliers, warehouses, ruling out the need of majority of tools and maintenance, with logistic cost reduction by 80%. The global market for additive to rise $37.2B[2]. The aerospace, automotive & medical industries have been the leaders in implementing Additive Technologies.

[2] Reference

The heavily regulated industries in the energy sector are catching up fast realizing the benefits of Additive through reduction of manufacturing lead time, improved product functionality through increased design flexibility and replacing production parts allowing on-demand manufacturing and even reduction in physical inventory. The goal to make decentralized and flexible manufacturing (build on demand at or near point of use) will help shift the industries from using AM for rapid prototyping to rapid manufacturing for production. The expected outcome includes performance improvement in the new product development and reduction in inventories and lead times.

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Industry envisions a B2B additive marketplace.

The positive impact of additive manufacturing on the reduction of lead time has given rise to an idea of building an industrial B2B marketplace for additively manufactured parts. It has been gaining support within the industry, specifically among the end-users of industrial products.

A central role of equipment manufacturers.

The concept of a B2B marketplace centers on using additive manufacturing to move from stocking physical inventory items of products to the management of digitized artifacts for prequalified parts, which can be produced on demand, possibly near the place of end-use. An exciting concept but filled with daunting challenges to realize, much more complicated than any open-source 3D Printing repository or web-based marketplace. However, the potential benefit to the industry overweighs complex challenges involved achieving it. The manufacturers of the industrial products must play the central role, since they own not only the intellectual property for both the products and the manufacturing processes, but also carry the liabilities and associated risks of failure in the operational use of the products.

Business & operational interests are critical.

Any B2B marketplace should sufficiently safeguard manufacturer business interests. New business and commercial models should be explored. The product manufacturer holds a wide variety of product portfolio, and the ones created additively often carry higher content of product and process intellectual property. Such a data resides in a highly secured and accessed control enterprise system.

System and data connectivity is needed.

The additive marketplace and manufacturers enterprise systems should be securely and seamlessly connected to enable necessary data transfer to enable effective use and broader adaption across the industry. Each company has its unique implementation of enterprise systems, and finding a common integration framework is neither easy, nor economical.

Prior to finding solutions for building common and flexible programmable interfaces, industry needs an agreement on the common data framework, which includes data model & supporting metadata, data quality and security plans, and over data governance policies.

More than 99% of the $12T global supply chain market still relies on traditional manufacturing techniques.

Additive technologies face complex set of adaption challenges.

Process barriers: Long material and product qualification cycle; higher cost due to new product development and added post processing, extra quality controls efforts; lack of collaboration of practices and procedures across the industry.

Knowledge barriers: The lack of awareness and understanding among the broader community of business leaders, engineers, technologist across the industries that the additive technologies can deliver industrial quality parts for highly critical applications. Limited information sharing on processes and material properties.

System barriers: The software systems used for the execution the additive processes are niche and work in isolation. They remain disconnected with the mainstream enterprise systems, such as CRM, ERP[1], PLM[1] used within the industries. The data created during additive lifecycle is complex and disparate.

Industry publishes standards for qualifying additive parts.

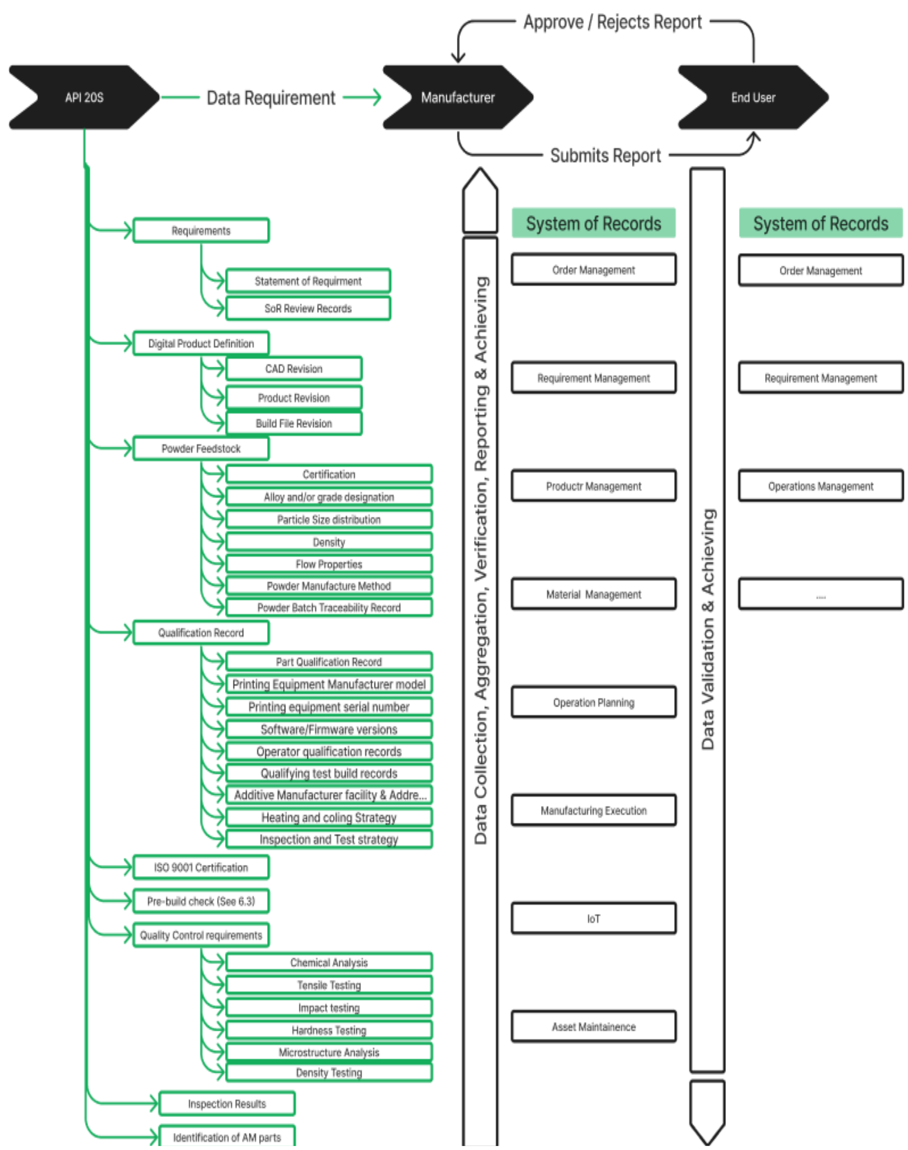
For past several years multiple standard bodies and committees across the industries working diligently to come up with set of guidelines for additive part manufacturers. Of recently, American Petroleum Institute (API) has published a set of standards (API 20S and API 20T) for additively manufactured parts.

The published standard requires from additive part's manufacturer an extensive set of data to deliver to the purchaser of the additive part. The standards list out requirements for collecting, tracking, reporting, and archiving data from the entire development and manufacturing lifecycle process of an additive part.

For an additive part's manufacturer to fulfill API's requirement, it must define a clear set of data collection and management strategy. This strategy must be built upon a robust data framework, which would help additive manufacturer to consistently and efficiently certify parts per the standard.

Defining a common data framework is extremely time consuming and resource intensive effort for an organization. Often it is expected from the industry committees or groups to come up with such standards. Build upon industry consensus a data framework could easily take years for a first draft version.

API 20S data traceability and reporting requirements.



API 20S/ 20T are American Petroleum Institute Standards. (api.org)

Baker Hughes has been at the forefront of leading the adaption of additive in energy industry.

Improving product performances and supply chain operations are the key drivers.

In Baker Hughes, substantial investments in past several years have allowed the use of Additive Technologies to take ground on sound footings, with proven realized benefits to product lines, from improved product functions and performance, reduction of cycle time, and overall simplification of supply chain and logistical operations. With the primary objective to support improved product performance and shorter lead times while maintaining the highest quality additively manufactured parts, there have been three key strategic components:

- finding product applications and business cases for the use of additive manufacturing
- building the experience and expertise in the additive technologies and supporting processes; and
- the use of digital to streamline & scale additive into broader product portfolio & business operations.

>10 years

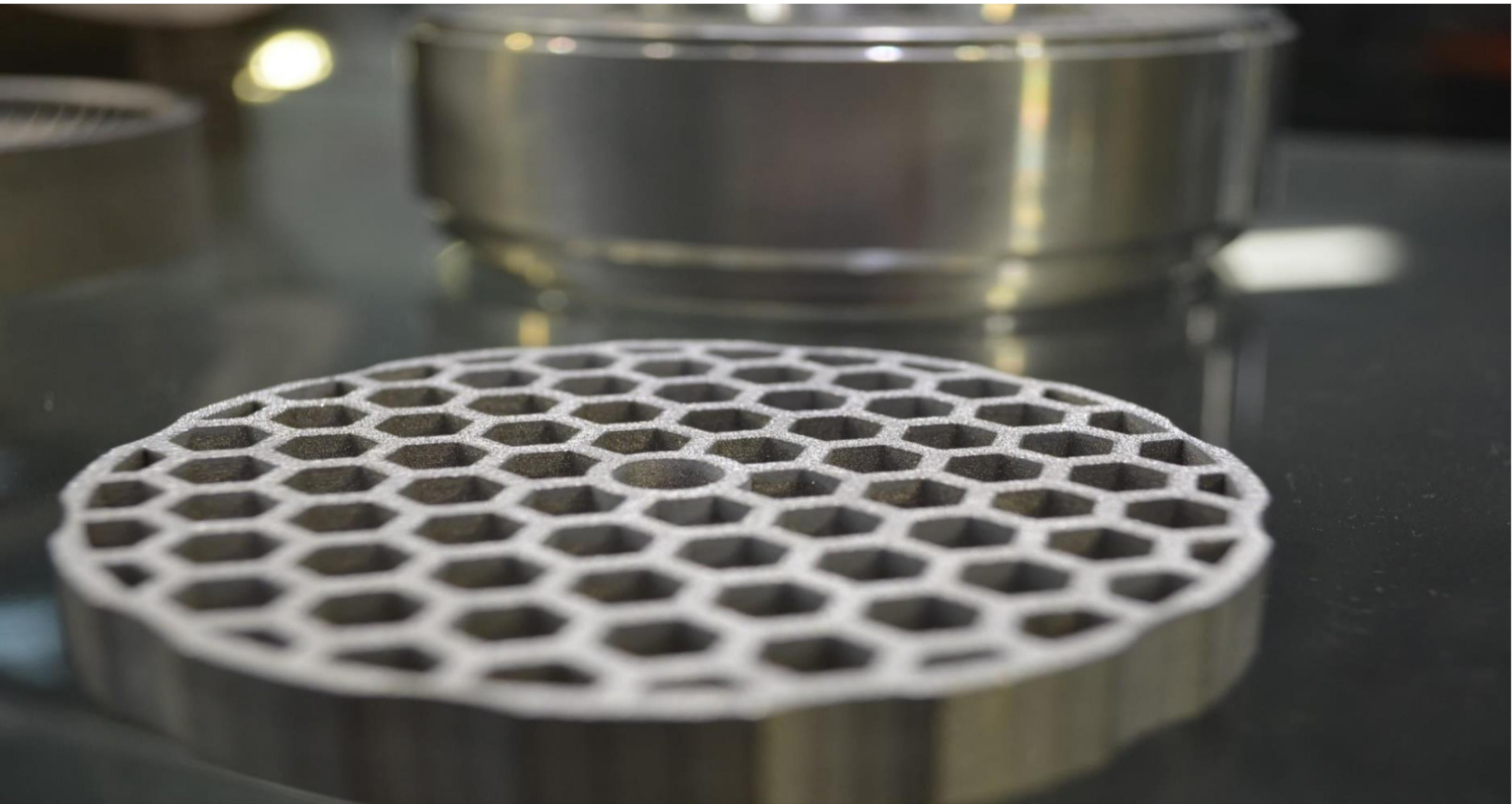
AM Development & Production

>1500 Parts

Qualified for Additive Manufacturing

6 Centers

Additive Research, development & Production



Digital plays a pivotal role.

Use digital to streamline additive lifecycle process.

At Baker Hughes Additive Services, the digital plays a central role in daily operations. The digital strategy for additive has three key components:

- a set of additive software applications and their efficient use
- end-end digital process integrated with company's broader digital ecosystem.
- Harness the value of the data through collection, aggregation, and analytics.

The journey to the digital strategy has resulted in numerous learnings, gathered from evaluating several commercially available software and platforms, and implementing a few within various additive process functions, The commercially available software for additive product development and manufacturing are innovative and contemporary in design, but lack the breadth required in the data model, which inhibits their ability to provide holistic end-end coverage to additive operations in an industrial setting, working in conjunction with broader business operations.

A key learning is the limitation of underlying data model and metadata in additive software platforms, keeping them disconnected not only from additive lifecycle but also from the mainstream enterprise systems, where bulk of daily business operations are executed.

A need for business centric data framework

In a business centric approach, the data required for achieving business objectives is the primary focus. A business centric approach requires understanding of overall business functions. How the functions are performed, what information flows among them and when.

A data framework manifest itself digitally.

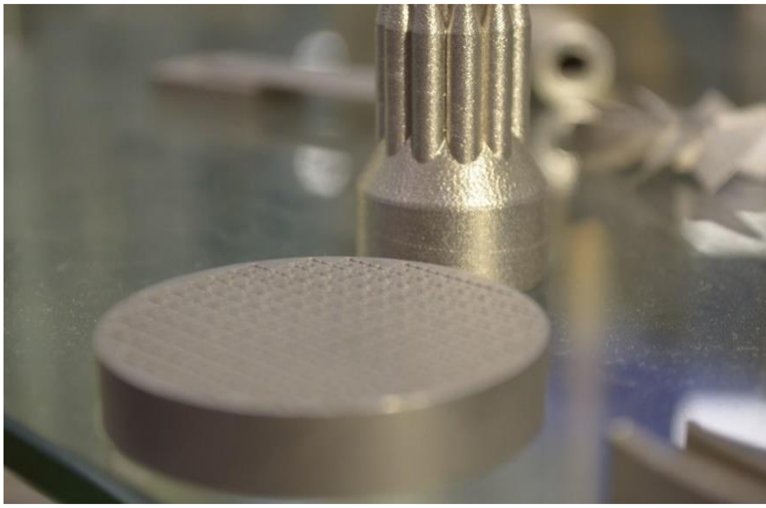
There are many commercial software platforms which offer capabilities to manage a digital workflow for additive process; however, the scope, feature set and underlying data model are generally limited and lacks the extensibility required to meet the extensive set of data requirements as laid out in the API standards; or the vision of the B2B additive marketplace. The software development primary focus on the additive technology improvements has been keeping the use of additive to either research and development activities with limited production parts among major manufacturers of industrial products; or to the service shops whose primary business to act as additive farms.

A shift to business centric approach

While the additive technology centric software development approach was needed during the incubation stage. For example, a printer job log data not connected to production orders or technical requirements or linked to subsequent post processing operations data loses business and overall operational context and provides a very localized value. To scale and be part of broader ecosystem, a business centric approach is needed. That means developing capabilities, feature set and extending data models to integrate additive processes seamlessly into broader business operational systems.

A need for more scholarship and research

Over the years there has been extensive research work published by academic institutions and standard bodies, such as NIST on the topic of data model for additive. The work primary focused on improving various functions within additive technology through improved interactions of the data created during the various stages. A much needed and very useful work, no doubt. [See reference section for list of samples of the published work.] There is, however, a still need for more work in defining ways to integrate additive technologies into the overall business design and manufacturing operations. The need to have well defined industrial data structure, relationships and data types is much needed.



A proposed additive data framework

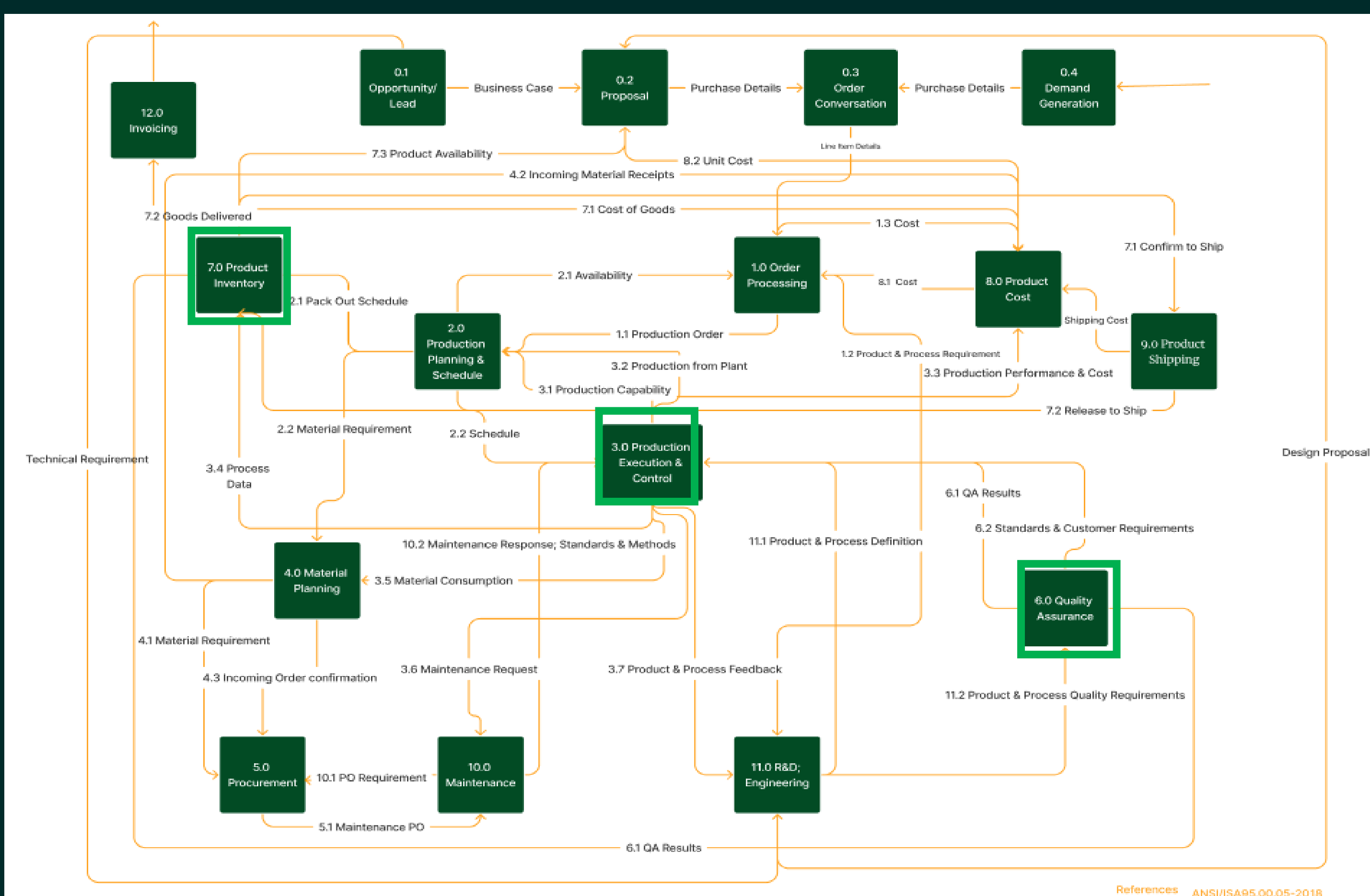
The proposed data framework will outline basic data structure, relationships and associated metadata, supporting data quality plan, and governance policies including rules for data ownership, access, security etc. required for an industrial additive marketplace, which not only provides additive value exchange among the industry partners through the management of digital inventory, but also a staged process of data collection and reporting and subsequent archiving highly critical parts requiring adherence to industry standards.

The proposed data framework will try to address the following key objectives:

- Allow additive process to integrate well with the rest of the business functions,
- Set basic data structure needed for the industry vision of the B2B industry marketplace (foundational to a digital inventory vision) and
- Enable additive manufacturers to achieve industry certification of highly regulated additive manufactured parts.

A data framework outlines the structured way of defining, describing, and documenting the data within an organization, or a company, or an industry – or within a domain. A data framework typical has four components.

1. *Data Model*
2. *Data Dictionary*
3. *Data Quality Plan*
4. *Data Governance Policy*



Part 1: Introducing an additive data model.

The goal behind defining the additive data model is to standardize the logical data structure that the applications involved in executing additive lifecycle process can use to run and integrates the same data with consistency, accuracy, and completeness across the broader digital ecosystem.

A standardized logical data model

The data model should facilitate integrations, interoperability, and overall useability with the broader ecosystem, composed of many enterprise systems executing multiple functions of business and operational processes. Equally important, as well, is the sustainability of the overall application ecosystem over time.

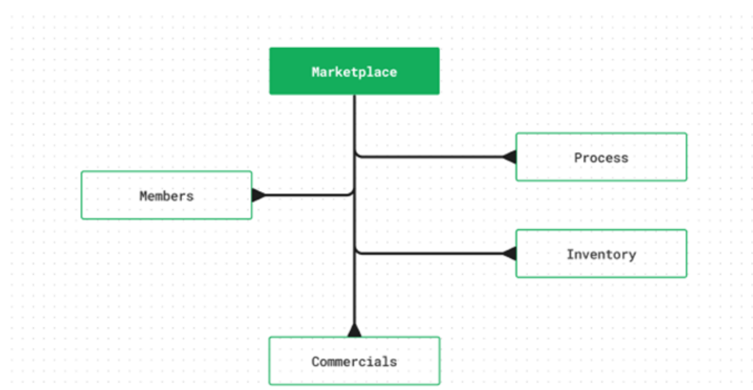
A shift to business centric approach

While the additive technology centric software development approach was needed during the incubation stage. To scale and be part of broader ecosystem, a business centric approach is needed. That means extending underlying data models to developing capabilities and associated feature sets that would allow additive software platforms to integrated seamlessly into broader business operational systems, while keeping the unique functionalities required for additive specific processes.

The foundational data model constructs

The highest-level construct in the proposal data model is the Marketplace, where industry participants collaborate in commercial exchange of value for certified additively manufactured products or services. The Marketplace object consists of four key building blocks:

1. Member
2. Process
3. Inventory
4. Commercial

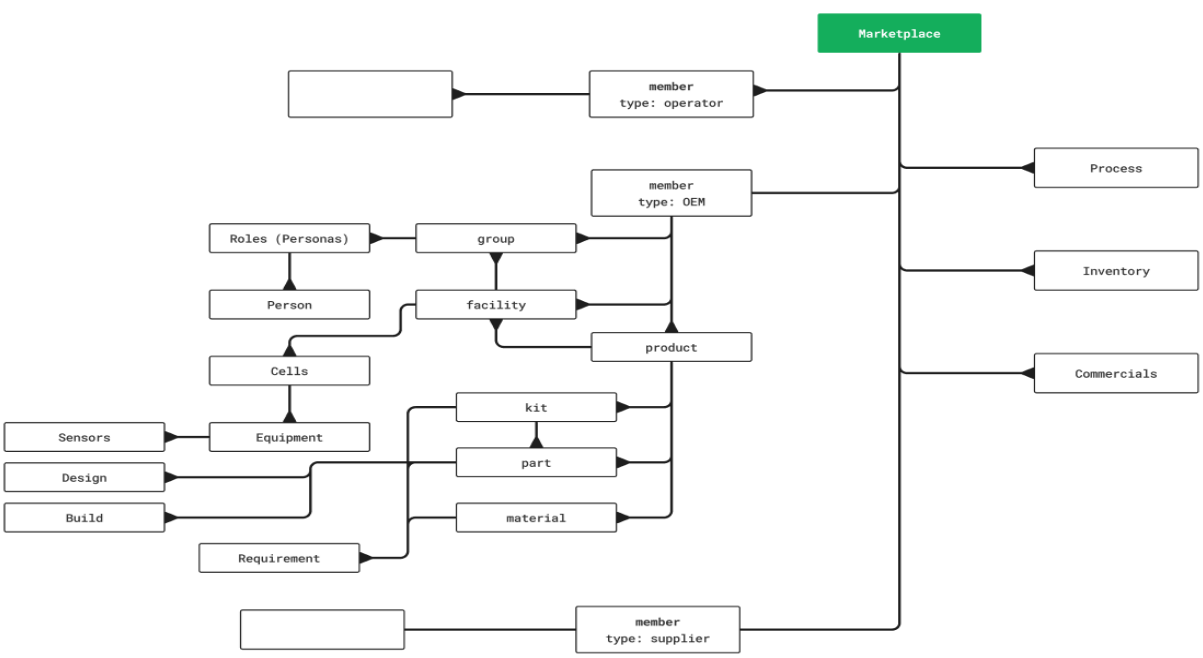


Part 1.1: A data structure to represent members.

The participant's companies in the marketplace are modeled as the Member. Each member (a company) could be a buyer or a seller (or both) of products and services. Each member can be of type end user of the products and services, product manufacturer, a service provider, or a supplier such as feedstock supplier.

Each member data block would in-turn carry people, plants (facilities), and products. Each member can have one or more facilities, where full service (design, develop, produce, inspect, and deliver) or partial service (for example post print machining or heat treatment) could be performed. Each facility is composed of cells which can have multiple equipment of various types, such as printers, heating furnace, lathe, CNC, etc.

The data relates to people stored in the Person block and their roles' related data is managed in Personas block and groups carries aggregate data representing teams, department, organization within company. Product could be sub-divided into types of products. The purpose here is not to create or duplicate full product hierarchy or structure managed in PLM[1] and ERP[1] systems. However, a product data block with the necessary metadata is needed to allow for proper data mapping and exchanges with enterprise systems, where master data will need to continue to reside. Currently, the commercially available AM lifecycle management platform offers little or no connectivity to the enterprise system – and thus leads to creation of disconnected product design data for additive. This is a big hurdle for integrating additive into broader enterprise ecosystem. The key here is not to duplicate features of PLM[1] or ERP[1], rather finding what is required to represent product

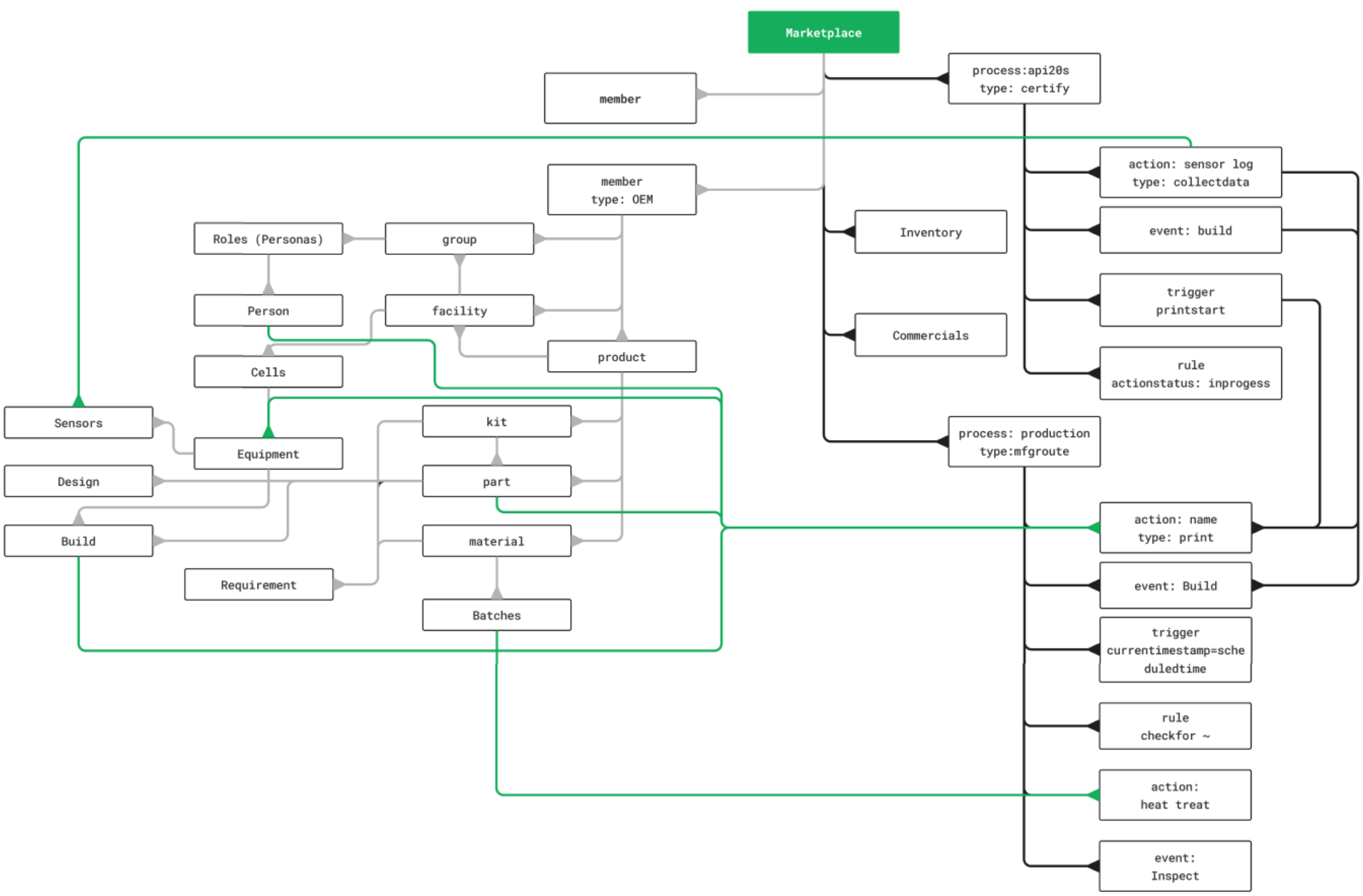


Part 1.2: A data structure to model processes.

Each type of equipment can perform actions, which would be defined and stored in the process block. The data to enable various types of operational processes to support one or more type of services is modeled in the process block. The development and delivery of the products follow a set of standard activities with required data (collection, sharing and archiving) modeled using the Process block agreed upon between two or more members.

An example of a process could be the API 20S certification process. **Another example of a process could be the management of digital inventory**.

The process composed of actions and events, which executed through various triggers and rules. These actions and their resultant events could be executed by people, equipment, and system behind the scenes.



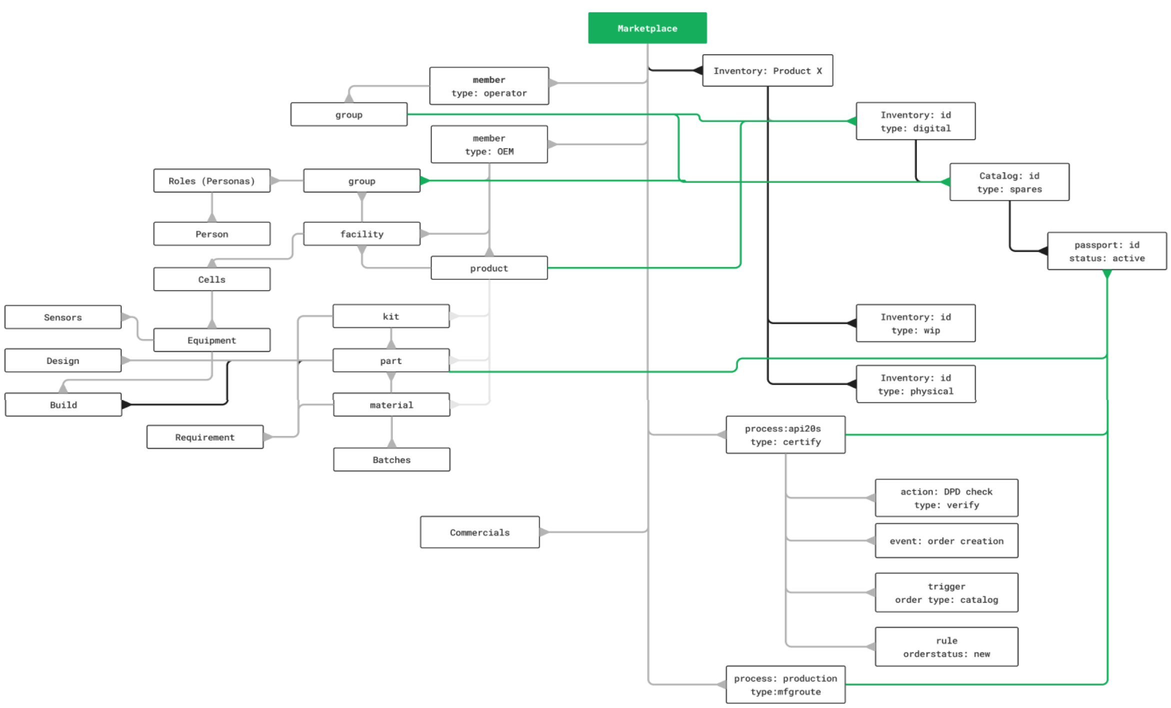
Part 1.3: A data structure for digital inventory processes.

The products exchanged between two members (buyer & seller) are managed within the Inventory data block, which carry pre-qualified digitized artifacts as digital passports ready to travel (move to production in a pre-qualified facility) on demand as per pre-agreed contract under commercial data block. While standard set of commercial could exist, however B2B marketplace often requires uniqueness between two companies exchanging product or services.

Inventory data can be of type digital, physical and work in progress. While core function of the proposed data model is to manage digital catalog items, the need for managing necessary physical or work in progress inventory data is to enable the overall process flow and connection to the enterprise system, such as ERP, where physical inventory master data would continue to reside.

Digital catalogs are the container objects for digital passports. Access to each catalog is defined at a group level. Multiple groups of with different personas from multiple member companies can have access to a same digital catalog, which lists out a specific set of digital passports, such as parts from same product families. Access to a digital catalog does not necessarily mean access to all the digital passport items in a catalog. Data governance policies outlines the roles, responsibilities and rules for data ownerships, access, security, and ethics.

Digital passport holds references to all the data required to produce the part repeatedly. Digital passport must carry version scheme to allow them to track changes in the reference data. When a part is order from a catalog, the pre-defined process actions should verify if any of the referenced has gone through the changes and should flag if changes have been made to the reference data.



Part 1.4: A data structure to model agreements among members.

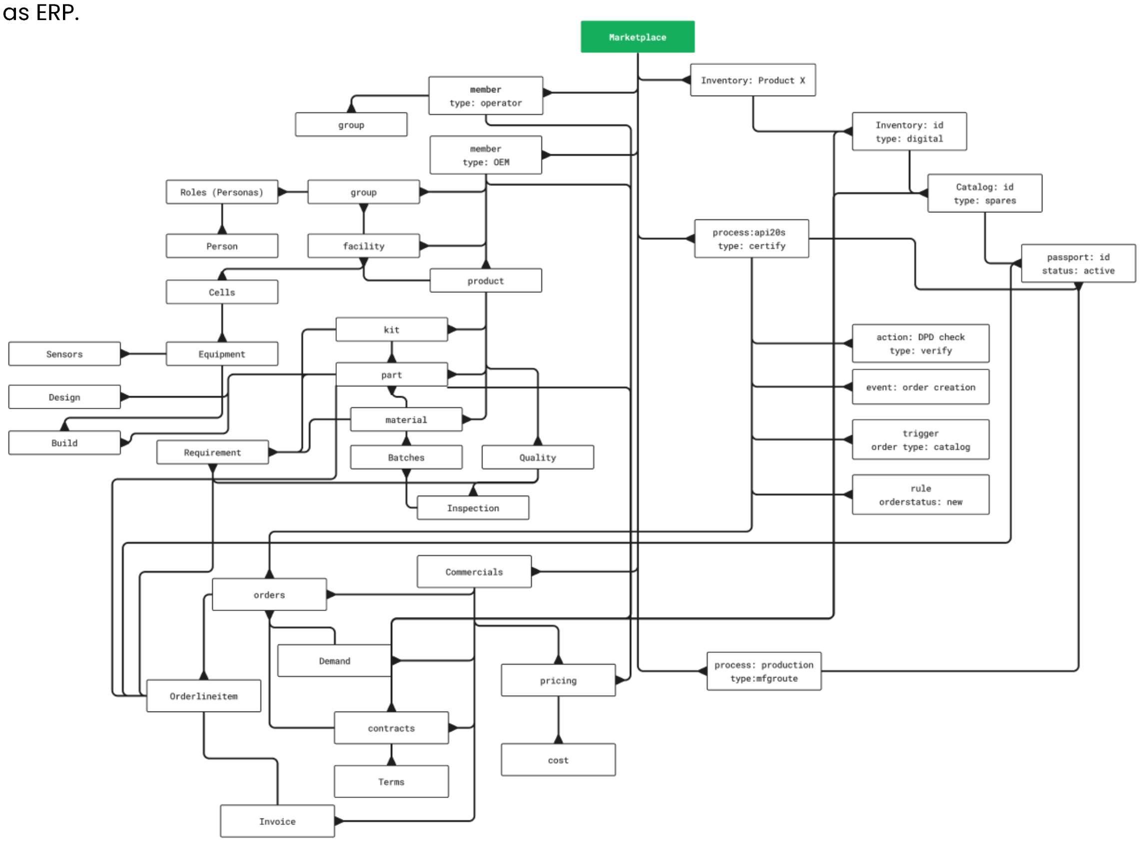
One of the key aspects of any marketplace is how it handles commercial exchanges of the product and services among its members. Each company manages commercials independently in its self-managed financial system. In the proposed additive marketplace model, goal is neither to replace nor replicate individual company financial system of records.

The purpose for outlining the structure for the commercial data is to manage agreements related additive products and services exchanges among the members of the marketplace, while working in conjunction with the existing financial system of records.

An application integration framework (not described here) should enable connections between the marketplace and an individual member's business planning and financial system, such as ERP.

The commercial object will have orders data, which will refer to the technical and business needs managed in the requirement object tied to the part details. Orders could be types, such as sales orders, production orders. A pricing object stores data for pricing strategy, which in turn holds a costing object. That would allow management of cost estimation data, which involve collecting information such as print time estimation to print volume to post processing details.

The contract object will manage the necessary data to help the repeat productions of fully qualified additive parts, managed through digital passports. A contract object related to the two or more members can be attached to the digital inventory and\or digital catalog objects.

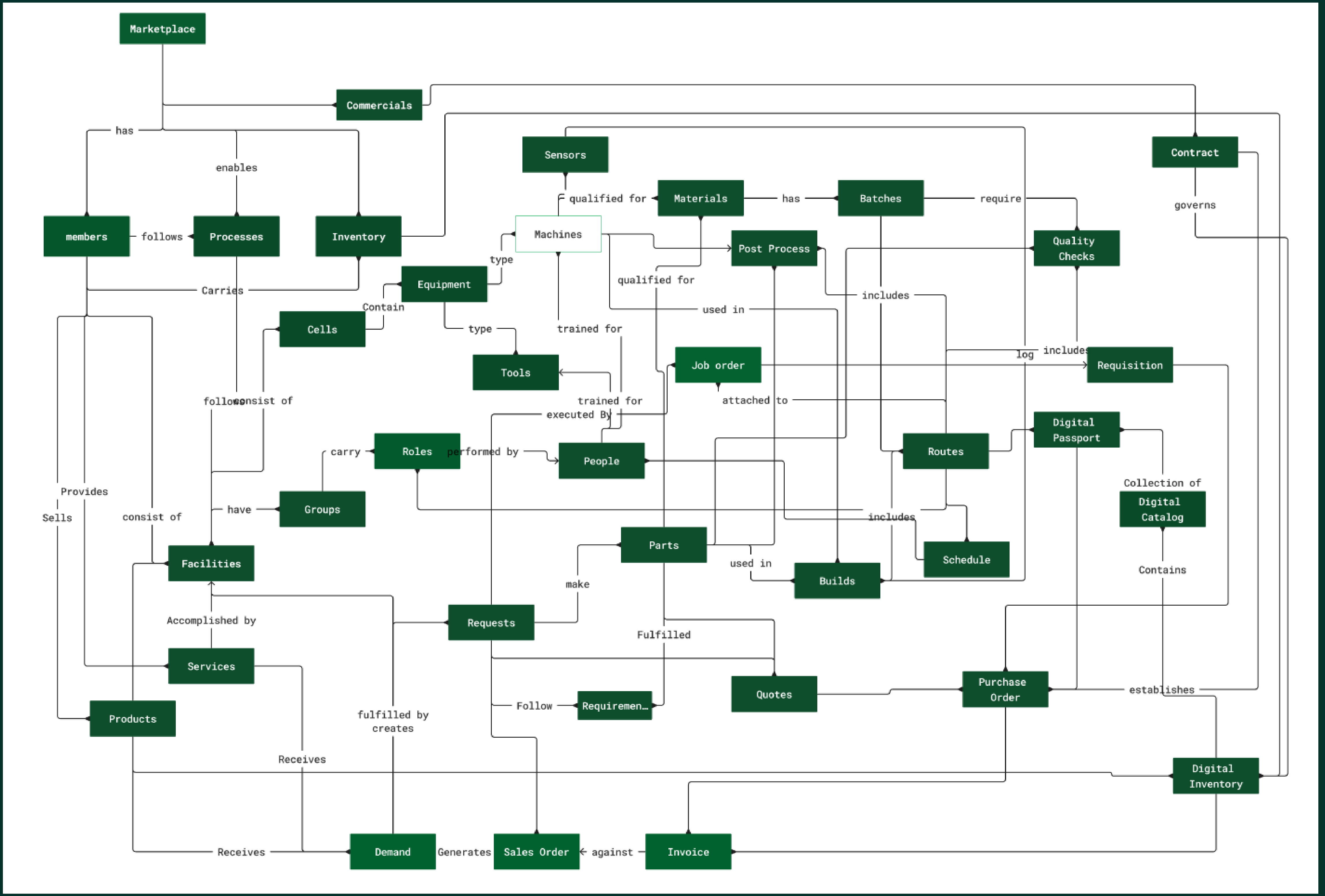


A semantic view of the conceptual data model

The relationship of four key foundation data blocks and their sub-types of objects can be represented using semantic language. [Figure 8.0] The highest-level construct Marketplace has member, inventory, process, and commercial data. The member (being a company) *consists of* facilities and groups; sells or buys products and services. Groups (being teams, departments, or organizations) can be attached to a facility, or can reside directly with the member structure. Groups carry roles (personas) performed by people, who are trained to use equipment (can be of types: printers, tools, or other machines, such CNC) in the cells under a facility, which follows set of (work) processes, such as execution of an order made between two members established through a contract defined under the commercials.

A demand (for example coming from a member's ERP) could generate a request (type: sales order) in the marketplace, for another member's facility (allowed under the contract) to fulfill. The request can carry requirements (type: technical, quality, business) must be met by an additive part(s). A price quote under the Commercial object is linked, for the requesting member to review and approve (predefined set of actions, events, conditions & rules). If approved, the process step moved to design stage.

Design data added to the Parts, which is used in for Build Design (has code for the printers & associated metadata). Build in turn is used in a manufacturing route (a type of process), which also includes Post Process, Inspect, & Quality. The route is attached to the job order (production order) linked to the original Request & Sales order. A Digital Passport for a Part has reference to the specific versions of all the data objects (such as route). A collection of digital passports makes up a digital catalog under the digital inventory – to which one or more contacts under commercial could be linked.



Conclusion

While the robustness of additive technology has progressed in past several years, its usage is still very limited within the industry as compared to traditionally manufacturing techniques. Our goal by publishing a data framework is to encourage the on-going industry dialogues about the need to scale the use of additive technologies and propose a path to help the industry achieve its business goals envisioned through an additive marketplace while also ensuring quality objectives are met through data data-driven certification process. We also hope to draw attention from software providers to relook at their current solutions and capabilities and find ways to incorporate industry needs more holistically.

The data model described is continuously evolving as more insights and experiences are gained into various aspects of business functions and processes. The next set of papers will continue to reflect these learnings through refinement and adjustment to the proposed data model, while continuing to provide deeper insights into the data structures, and interrelationships among data types. Subsequently, the paper will also address the needs of the data quality and governance plan to encompass remaining elements of the data framework.

One of the key differentiating aspects of the data model proposed is that it is meant for a formal production structure in a regulated industry, where multiple companies would transact under the common data structure required for its transactional compliance.

This data framework is not meant for the hobbyist printing a niche part from a cloud base marketplace where the interaction structure is limited in personas. That is why the process, inventory and commercials data are not within the domain of a single member company block, as seen in the enterprise systems currently used within the companies. That is one of key limiting factors among the enterprise systems to be used as cross-company B2B industry platform. It complies with regulation requirements, and protect all participants interests, from the commercial, legal, and intellectual properties rights.

Glossary:

1. AM: Additive Manufacturing
2. CRM: Customer Relation Management System
3. PLM: Product Lifecycle Management
4. ERP: Enterprise Resource Planning
5. MES: Manufacturing Execution
6. IoT: Internet of Things, refers to a network of physical devices, such as printers.

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Faisal Iqbal is the Digital Product Leader for Baker Hughes Additive Services. In his role, Faisal is responsible for the management and development of Digital Platform to industrialize Additive Technologies inside and outside Baker Hughes.

Faisal has over twenty years of experience across Automotive, Energy, & Oil & Gas. During his career he has held various leadership roles driving the digital product development impacting productivity & quality improvements, increased revenue, and overall user experience.

Faisal is passionate about the use of technology & data to drive new ways of thinking, working, & living; a better, safer, and more creative world promoting entrepreneurial endeavors.