IFC-based cut & bent rebar supply chain integration

Maciel, Alex R. [a] and Corrêa, Fabiano R. [b]

Escola Politécnica, University of São Paulo, Brazil
E-mail: [a] alex_roda@usp.br , [b] fabiano.correa@usp.br

Abstract –

Despite the growing interest towards the Building Information Modelling (BIM), its widespread use in the entire life cycle of construction products is still incipient. In most of the cases, BIM is not properly used, in an integrated manner, with suppliers and manufacturers of custom building components. The BIM-based digital fabrication of custom building components should be one of the main beneficiaries in changing its old processes to embrace BIM. This fact could be related to the lack of solutions that allow the effective reuse of information contained in the BIM model, especially in supply chains arrangement wherein distinct stakeholders provide key information. This is the case of the Brazilian cut & bent reinforcing bar supply chain in which the interface between the rebar fabricator and the engineering firm are carried out by a General Contractor. Although the available standards allow the exchange of reinforcement data from the design to the fabricator's automated CNC-controlled bending machines, it do not support the input of contractor's requirements, such as reinforcement delivery schedule. Focusing on the Brazilian cut & bent rebar supply chain for Cast-in-place concrete, this article explores the use of the IFC to hold the process and control requirements provided by the contractor. The procurement and planning requirements were identified and presented this way. Alongside, a proposition was made to represent in IFC the information required by the rebar fabricator so it could be reused in their industrial environment. Finally, some suggestions are provided to improve the integration among agents that act in this process.

Keywords –

IFC; Reinforcing bars; Supply Chain;

1 Introduction

The Building Information Modelling (BIM) has shown steady worldwide expansion among the AECO industry [1] motivated by its inherent benefits or by the demand of public and private contractors. Despite the advances in its adoption, the use of BIM is still more concentrated in the pre-construction stages, such as design, 3D coordination, quantity take-off and construction planning. It is still not properly used, i.e., in an integrated manner, with suppliers and manufacturers of customized building components.

BIM-driven prefabrication or digital fabrication is pointed out as one of the processes that should clearly receive most benefits in the change [2], especially for engineered-to-order and make-to-order building components. While well established in some sectors such as steel structures, digital fabrication is still underused in the Cast-in-place (CIP) reinforced concrete industry, particularly in regional supply chain configurations wherein the design and fabrication stakeholders do not act together.

Initiatives, such as those promoted by the North American market, which culminated in the publication of the ACI 131.1R-14 standard [3] (Information Delivery Manual for CIP concrete), demonstrate the effort to improve interoperability throughout the CIP reinforced concrete domain, based on international open and non-proprietary standards as the Industry Foundation Classes (IFC). However, for global IFC-based supply chain integration, it is necessary to consider the diversity of configurations that the supply chain presents between different countries.

This is the case in the cut and bent reinforcement bars supply chain, which although has similarity about the key agents involved in the design, detailing, procurement, fabrication, delivery, stock and assembly of the reinforcement bars, the configuration may present itself in different arrangements, influenced by regional practices and standards, project delivery methods and stakeholder's relationships [3] [4] [5] [6] .

According to regional practices, the rebar detailing can be performed by distinct agents. In some countries, such as in the US [7], it is carried out by the fabricator or under his supervision (Figure 1a). Conversely, in other countries, such as in Brazil [4], the rebar detailing is fulfilled by the structural designer without the participation of the rebar fabricator (Figure 1b) and the interface between them is intermediated by the Constructor or the General Contractor (GC).

The "detailing-fabrication" segregation makes more complex and less efficient the digital fabrication based on available standards.
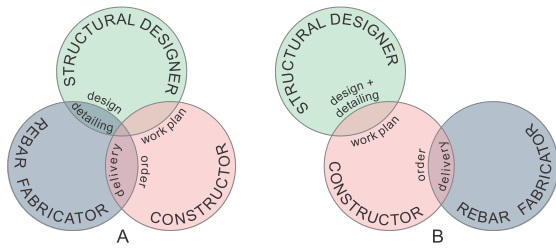
Figure 1. Rebar detailing according regional practices

Focusing on the Brazilian cut and bent rebar supply chain, our research aims to enable the rebar fabrication via IFC-based digital fabrication.

This paper presents how the reinforcement work planning and the rebar purchase order defined by a third-part stakeholder can be described in IFC4 by means of the IFC kernel control and processes extension. It is a further development of the author's previous work [8], where it was demonstrated how reinforcement data, required by CNC-controlled cutting and bending machines, could be mapped in the IFC schema.

2 Brazilian cut & bent rebar supply chain in BIM context

In the configuration of cut & bent rebar supply chain typically adopted by the Brazilian market, structural engineering firms usually do not have a direct relationship with the rebar fabricator, even though it is responsible for both design and rebar detailing.

The interface between the designer and the fabricator is carried out by the Constructor or the GC [4]. Besides acting as an intermediary between these agents, they have the responsibility of the orders and delivery schedule coordination in accordance to the construction planning.

Collaboration between stakeholders becomes even more segregated in the case of public sectors contracts, often regulated by Design-Bid-Building (DBB) project delivery approach, and the rebar detailing is fulfilled by the structural engineering firm, under the supervision of the owner or his designated representative.

The current workflow is highly focused on paper-based documents, albeit generated through digital tools. The rebar placement drawings prepared by means of 2D CAD tools are submitted to the Contractor, which then forwards it to the rebar fabricator in conjunction with the purchase order via e-mail, spreadsheets or forms templates. It is up to the rebar fabricator to convert the design and order information into production data, a highly manual and error-prone task.

This workflow brings "islands of automation" connected by manual data transfer [9] where the fabricator, although already had the technological infrastructure to receive this data in digital format and reuse directly in its automated industrial system, has to recreate the reinforcement data manually before being the fabrication.

In contrast to the current approach, the use of BIM promotes an integrated and collaborative workflow, which favors the data reuse and the decision-making process with consistent and integrated information, throughout the cut and bent rebar supply chain.
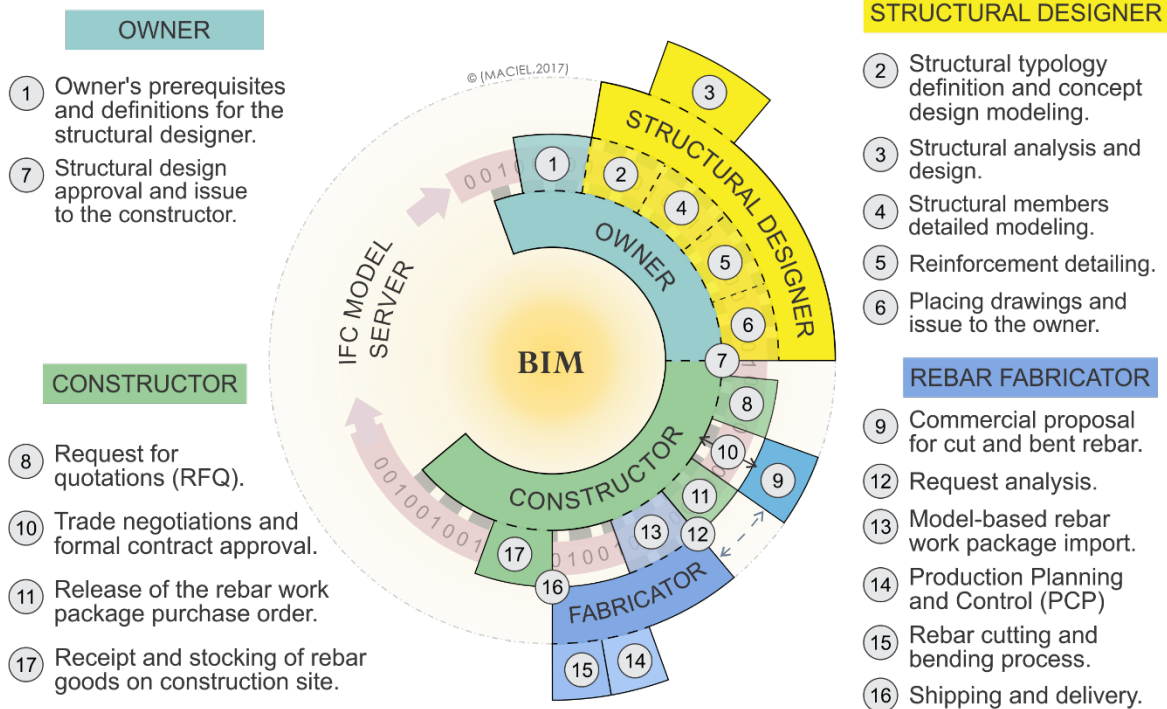

Figure 2. Brazilian cut and bend rebar supply chain in BIM context

The BIM model represents a common and shared database that evolves gradually along the project life cycle, and is updated by distinct stakeholders, as shown in Figure 2.

Coordination and approval activities, although not explicitly represented in the proposed workflow, occur based on the BIM model.

In the design phase, it is mainly used for modelling general structural elements (task 1 to 4), and not often used in the reinforcing detailing. Therefore, other supported BIM uses such as, 3D coordination, or 4D planning, are limited.

The consolidation of BIM in the reinforcement detailing process (task 5 and 6) promotes new possibilities for the downstream activities' stakeholders, enabling the reuse of reinforcement data created in the design phase throughout procurement (task 8 to 10) and rebar fabrication (task 12 to 16).

3 IFC-based cut & bent rebar supply chain integration

Despite the availability of standards such as the BVBS [10], which allows the digital exchange of the reinforcement data, current standards are focused on the end-to-end interface and do not enable the collaboration of all stakeholders of the cut and bent rebar supply chain. It is limited to the unidirectional data transfer from the designer's BIM/CAD rebar detailing authoring tool to the rebar fabricator.

The current standards prove to be most effective in cut and bent rebar supply chain configuration wherein the designer and the fabricator has a direct relationship or when the rebar detailing is performed by the fabricator. However, when these agents do not directly collaborate, the use of digital design-fabrication interface based on the current standards requires high synergy.

When acting as an intermediary, the Constructor or GC may choose to use the same authoring tool to include their requirements; otherwise, it is in their liability the management of multiple documents with distinct files formats (including updating new information), in addition to provide the procurement and delivery requirements.

An example of the proprietary BIM tool [11] that allows the rebar integrated workflow is presented in the Crusell Bridge project [2]. In this case, some parts of the proposed workflow are supported natively, while others required the use of third-party add-ins.

To reduce non-valuable added activities for data re-interpretation and re-entry of information [12], the need for additional tools or manual intervention prior to the rebar fabrication, it is important that existing standards be improved or new standards be developed [13]. In order to maintain compatibility with the existing cutting and bending machines and operating plants, it is recommended that these actions be done in parallel.

In alignment with others AECO sectors, the adoption of the Industry Foundation Classes standard (ISO 16739:2013) is considered appropriate to support the cut & bent rebar supply chain exchanges. In this regard and aiming to enable a wide-range IFC-based supply chain integration, it is necessary to represent the procurement, planning and production definitions inside IFC files.

From the rebar fabricator's viewpoint, the production data requirements can be subdivided into two data sets according to the source who provides them.

The first data set consists of the rebar geometric definitions shape and quantity requirements, provided by the designer, and which will be used in the CNC-controlled bending machines. In a previous work [8], it was proposed a mapping of the requirements predicted by the BVBS [10], the most widely used standard for cutting and bending machines [13], in the IFC schema.

The second data set contains the contractor's purchase order and delivery schedule requirements which are the central point of this paper.

The discussion below is limited only to constructor and rebar fabricator interface (tasks 11 and 17), excluding from this analysis the commercial transitions.

3.1 IFC kernel process extension

Included in the IFC core layer structure [14], the IFC kernel extensions introduce basic and primary ideas for the entities derived from *IfcObjectDefinition* that are related with the concept of products, processes or control.

While the product extension handles items that have geometric and spatial context, including physical items (e.g. components, building elements) and non-physical items (e.g. spaces, grids, annotations), the process extension captures the workflow concept required to perform an execution or to support construction activities.

Work tasks and activities with time-ordered logical sequence are mapped in the IFC4 schema by means of the *IfcProcess* subtypes: *IfcTask*, *IfcEvent* and *IfcProcedure*. These process entities should be also linked to a specific entity-type, which defines common characteristics to a particular kind of process or activity. Exception to this rule is the schedule or time assignment, which should be defined at the object-occurrence level.

The *IfcTask* entity represents units of work that will be performed in the construction project, including building and product installation activities as well as order actions, move operations, design and others construction related activities.

An *IfcEvent* describes an occurrence that may happen and triggers an action or response.

An *IfcProcedure* denotes a logical set of actions in response of an event, or to cause an event in particular in a stepped process.

Inherently, a process transforms inputs into outputs, and may cause the spending of resources. Products used as inputs (*IfcProduct* subtypes) and resources consumed (*IfcResource* subtypes) can be assigned to the process entities through the relationship *IfcRelAssignsToProcess*.

According to their purpose, tasks can be nested within subtasks or procedures, as well as with other tasks in order to represent its hierarchy. The logical sequence among process entities is modeled by the *IfcRelSequence* relationship, describing a predecessor-successor relation and time lag between two entities.

Tasks must be declared in the project context when representing a root-level task. Otherwise, they should be ascribed to the *IfcWorkControl* subtypes to provide a schedule of work task (*IfcWorkSchedule*) and its related work plan (*IfcWorkPlan*).

Moreover, the entities derived from *IfcProcess* may be assigned to the control *IfcWorkCalendar* entity in order to establish working and non-working time periods.

3.2 Reinforcement works planning

According to their size, cast-in-place reinforced concrete structures are commonly partitioned into several work packages by floor or concrete pour phase in order to facilitate their execution. There is not always a correlation between the pours package extension and the physical structural members set [15].

Each work package is then breakdown, composing specific and interdependent work packages as formworks, reinforcement works, MEP embedded and concrete placements, each one with a particular work schedule, set of subtasks and a specific supply chain.

The schedule of each specific work packages is described in IFC4 schema by an *IfcScheduleWork* and aggregated into their respective work plan (*IfcWorkPlan*) which represents a production phase. These entities are also used to control the planned, baseline and actual scheduling of the construction. A proposal to IFC-Based schedule and progress updating is present by [16].
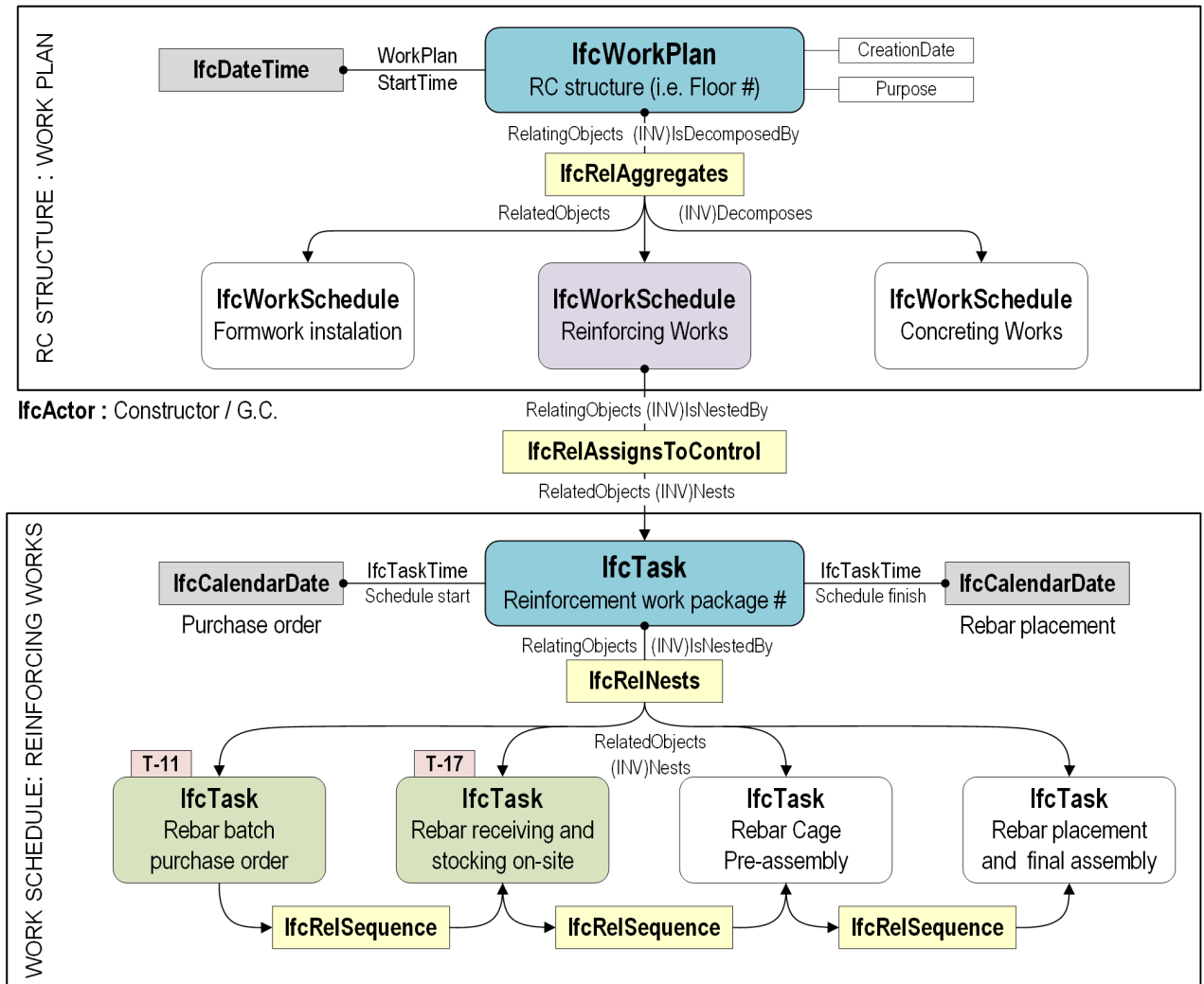

Figure 3. IFC-based reinforcement work package planning

Targeted at the concrete casting expected date, the planning of each rebar work package must predict the lead-time of the procurement, fabrication and delivery of rebar goods besides the time needed for rebar cage assemblies and rebar placement deadline, considering the interrelationship with the others work packages.

In Figure 3 it is shown how a typical workflow of reinforcing works may be described through the IFC4. The reinforcement work package (summary task) has a set of sequential nested subtasks tied to the main task. Each work unit represented by an *IfcTask* entity has a logical sequence and a start/end schedule allocated.

From the perspective of the cut and bent rebar supply chain, its last activities are represented by the delivery of the rebar goods (Task 16) and receipt/stocking at the construction site (Task 17) as shown in Figure 4.

The unloading and subsequent stock of the rebar packages are part of the first activity performed by the construction crew. This task concerns a set of internal logistic activities that precedes the rebar cage pre-assembly and their final placement.

The start date assigned to this task denotes the scheduled delivery date to be reported to the rebar fabricator at the purchase order.

Although unloading and storage of the rebar goods are usually carried out on the same day of delivery, according to [4], the cut and bent rebar commonly remains stored for 15 days before its final positioning.

The same author concludes that this fact may reveal inefficiency in the planning and control process of the activities performed in field given the reliability of the delivery by the rebar fabricator.
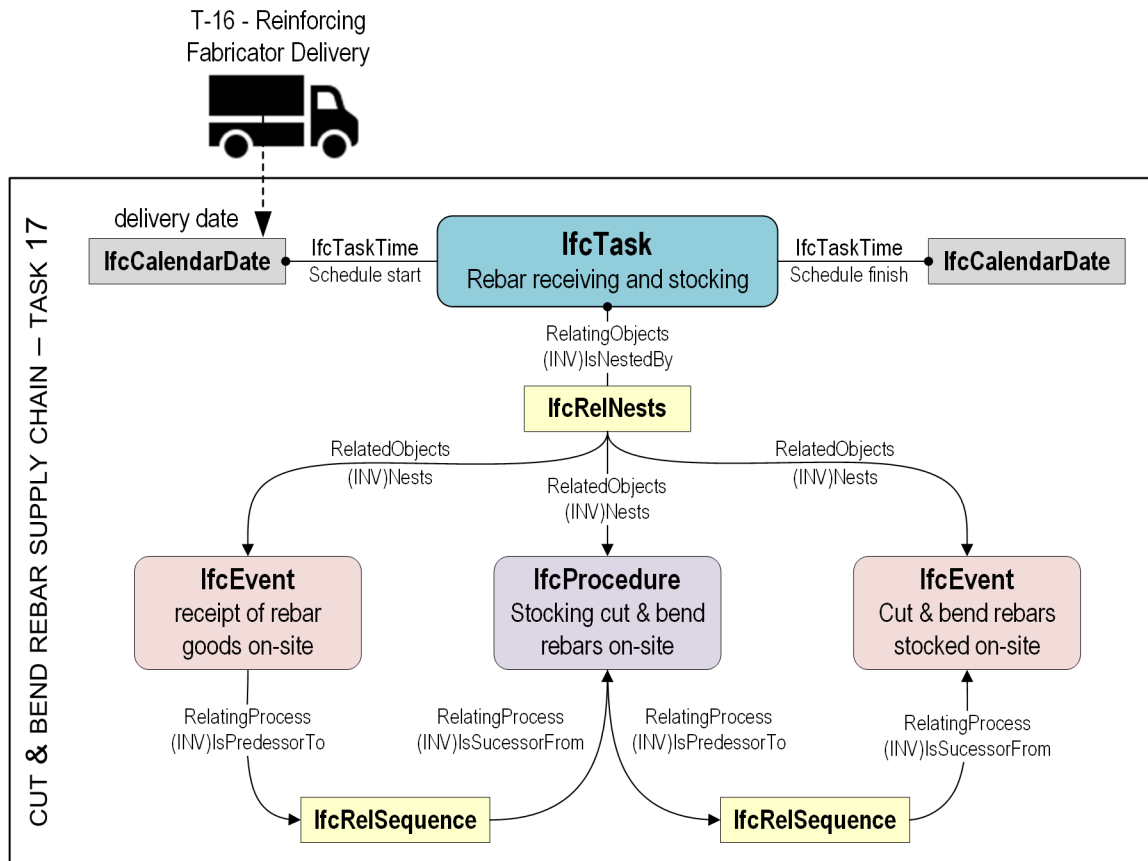

Figure 4. IFC-based rebar receiving and stock on construction site.

3.3 Reinforcement order

Based on the expected delivery deadline it is up to the construction manager to formalize the purchase order of the respective rebar work package considering lead-time required by the rebar fabricator.

The order process consists of selecting the reinforcement that composes the work package and assigning them to the respective purchase order, including the desired delivery date.

In the traditional paper-based workflow, the contractor merely forwards the corresponding placing drawings set to the rebar fabricator along with the purchase order form.

This workflow requires that the rebar fabricator transcribes the design and planning data into production data before the rebar processing. In some cases, the placing drawings need to be partially produced in accordance with the pour break requirements and entail an additional effort on the part of the fabricator to reckoning the correspondent rebar set.

By contrast, a BIM-based workflow besides providing reliable rebar detailing and coordination, when properly used in an integrated manner with the constructor and the rebar fabricator can contribute to improving the rebar digital fabrication establishment, mainly for a tripartite supply chain configuration such as the Brazilian one.

Figure 5 represents the proposal from the authors for IFC-Based order exchange.

The *IfcTask* "rebar order" summarizes a set of activities performed by the constructor, GC or your subcontractor to formalize the rebar request.

The first procedure is correlated with the concrete pour extension. It is done concurrently with the other work packages planning (e.g. formworks, concrete placement), considering productivity rates and constructability.

Once defined the concrete pour phase limits, the delivery schedule requirements and respective rebar set, the purchase procedure is effectively started.

The assignment of the rebar set from the rebar detailed model for this *IfcTask* is modelled through the relationships *IfcRelAssingnToProcess*.

Finally, the purchase order (depicted by the *IfcPurchaseOrder* entity) is assigned to the rebar order task by means of the relationship *IfcRelAssingnToControl*.

Furthermore, it should be indicated the organization that is issuing the request and who will be contracted to fulfill the order.
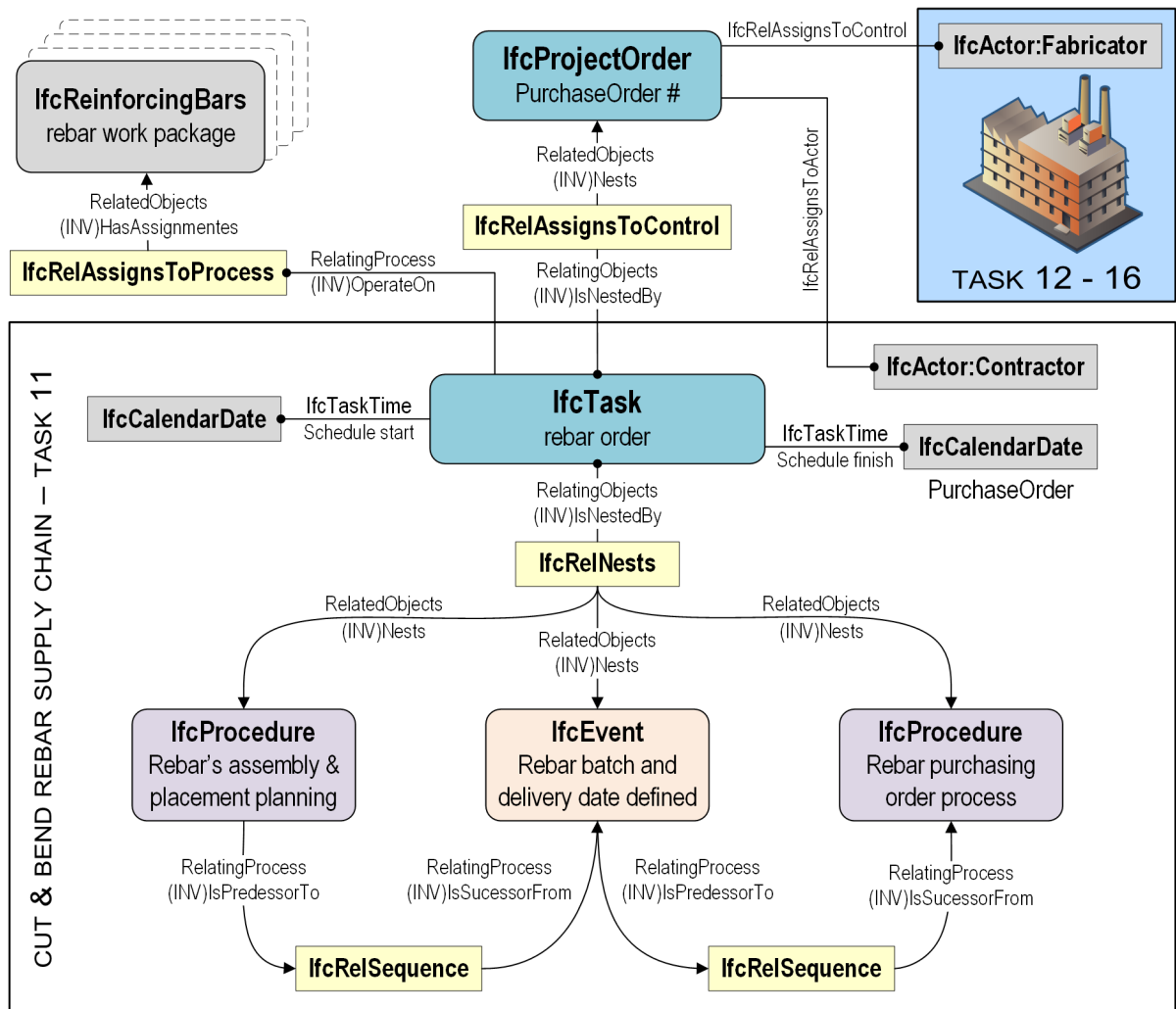

Figure 5. IFC-based rebar work package assignment and purchase order

An *IfcProjectOrder* represents directives for performing a service or purchasing a product which are also typically associated with formal contracts between two organizations [14]. It is a control entity belonging to IFC interoperability layer *IfcSharedMgmtElements*.

It contains the *Ifc.ProjectOrder.PredefinedType* attribute, which should be filled with the enumeration value PURCHASEORDER (*IfcProjectOrderTypeEnum*) to configure a purchase order for a good or service.

This entity has a unique identifier (GUID), name, description and revision control associated. The purchase order identifier is set in the *IfcProjectOrder.Identification* attribute.

Any changes, represented by other *IfcProjectOrder* instance, could be associated to the original purchase order, through the relation object *IfcRelNest*, and indicated by the enumeration value of CHANGEORDER to the *PredefinedType* attribute.

In some cases it is required by the rebar fabricator to know in advance if there is any restriction of access to the site, as limits for truck size, which should be informed by the *ShipMethod* property included in *Pset_ProjectOrderPurchaseOrder*.

4 Conclusions

In this article, an IFC-based integration for the cut and bent rebar supply chain was proposed, wherein the design-fabrication interface is performed by a third part.

Focusing on the configuration adopted by the Brazilian market, it was presented how the rebar planning and order can be properly described in the IFC schema.

Notwithstanding the availability of proprietary BIM tools that allow the proposed workflow, some parts natively or via Application Programming Interface (API) as a whole, the authors consider that widespread supply chain integration should rely on neutral standards, such as the IFC.

By demonstrating the potential use of IFC to support downstream supply chain activities, the authors attempted to contribute to the development of tools that improve the constructor's planning and the specification of rebar orders activities, aiming to reduce the occurrence of inaccurate orders, which is one of the most cited problems in the Brazilian market [4].

Currently, these workflows are not covered by the IFC4 official buildingSMART Model View definitions (MVD) [17]. However, they may be addressed in future reinforcement CIP domain specific MVD's development.

Through the establishment of BIM processes in the rebar detailing, procurement and planning, as well as the IFC consolidation and MVD development, there are opportunities to expand the digital fabrication on the CIP reinforced concrete domain.

It is expected that the development of new tools that allows the rebar fabricator to access and reuse data contained in the IFC model, as illustrated in Figure 6, would reduce considerably the production lead-time. Reports obtained from interviews done by one of the authors show that this period corresponds to about 15% of the rebar fabricator's lead-time.
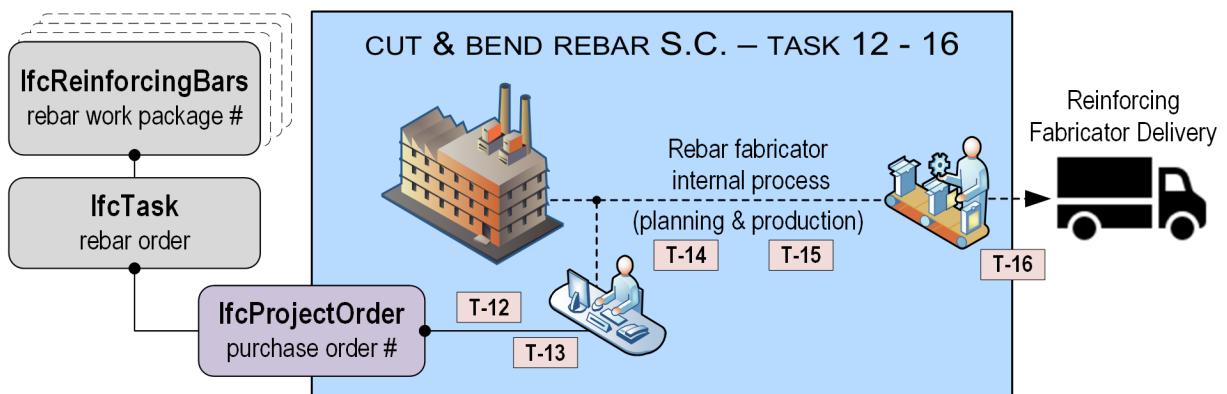

Figure 6 – IFC-based rebar fabricator interface

5 References

[1] McGraw Hill Construction. *The business value of BIM for construction in major global markets: how contractors around the world are driving innovation with Building Information Modeling*, McGraw Hill Construction, Bedford, USA, 2014.

[2] Eastman C., Teicholz P., Sacks R. and Liston K., *BIM handbook: a guide to building information modeling for owners, managers, designers, engineers, and contractors*, 2nd edition, John Wiley & Sons, Hoboken, New Jersey, USA, 2011.

[3] American Concrete Institute, *ACI 131.1R-14: Information Delivery Manual (IDM) for Cast-n-*

Place Concrete, ACI Committee 131, Farmington Hills, MI, USA, 2015.

[4] Isatto E., Azambuja M. and Formoso C. The Role of Commitments in the Management of Construction Make-to-Order Supply Chains. *Journal of Management in Engineering*, 31(4):04014053, 2015.

[5] Polat G. and Ballard G. Construction supply chains: Turkish supply chain configurations for cut and bent rebar. In *Proceedings of the 11th Annual Conference of the International Group for Lean Construction*, Virginia, USA, 2003.

[6] Clevenger C. and Khan R. Impact of BIM-Enabled Design-to-Fabrication on Building Delivery. *Practice Periodical on Structural Design and Construction*, 19(1):122–128, 2014.

[7] American Concrete Institute, *ACI 315-99 Details and Detailing of Concrete Reinforcement*, ACI Committee 315, Farmington Hills, MI, USA, 1999.

[8] Maciel A. and Corrêa F. Interoperability with IFC in the automated rebar fabrication. In Proceedings of the 33rd International Symposium on Automation and Robotics in Construction (ISARC), Pages 872–880, Auburn, USA, 2016.

[9] Navon R., Rubinovitz Y. and Coffler M. Reinforcement-bar manufacture: from design to optimized production. *International Journal of Computer Integrated Manufacturing*, 11(4):326–333, 1998.

[10] BundesVereinigung der BauSoftwarehäuser. *BVBS - Guidelines: Exchanging Reinforcement Data - interface description release 2.0*, BundesVereinigung der BauSoftwarehäuser E.V., Bonn, Germany, 2000.

[11] Trimble. Modeling for Efficient Rebar Production and Assembly. On-line: https://www.tekla.com/solutions/rebar-fabricators/, Accessed: 10/05/2017.

[12] Froese T. Future directions for IFC-based interoperability. *Journal of Information Technology in Construction*, 8:231 –246, 2003.

[13] Aram S., Eastman C. and Sacks R. Requirements for BIM platforms in the concrete reinforcement supply chain. *Automation in Construction*, 35:1–17, 2013.

[14] buildingSMART, Industry Foundation Classes Version 4 - Addendum 2. On-line: http://www.buildingsmart-tech.org/ifc/IFC4/Add2/html/, Accessed: 10/05/2017.

[15] Barak R., Jeong Y., Sacks R. and Eastman C. Unique requirements of building Information modeling for cast-in-place reinforced concrete. *Journal of Computing in Civil Engineering*, 23(2):64–74, 2009.

[16] Hamledari H., McCabe B., Davari S. and Shahi A. Automated Schedule and Progress Updating of IFC-Based 4D BIMs. *Journal of Computing in Civil Engineering,* 31(4):04017012, 2017.

[17] buildingSMART. MVD Releases. On-line: http://www.buildingsmart-tech.org/specifications/ifc-view-definition/, Accessed: 10/05/2017.