Sustainability assessment within a design process

An analysis of the impact of sustainability assessment within a design process

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VIBES BUILDING ENGINEERS

Acknowledgements

During my search for a thesis topic I quickly discovered my interests were at investigating business processes of companies working in the field of civil engineering. Thanks to my University professor Timo Hartmann I quickly got hold on a very interesting topic. During the following months conducting my research I gained insights about my research topic, how to conduct a thesis, and I learned a lot about myself.

This experience wouldn't have been realized without the support of a lot of people. First I would like to thank my parents, who supported me every minute of the day and kept believing in me. Next I would like to thank Timo Hartmann and the employees at Vibes building engineers for assisting me in realizing my research. Finally I would like to thank all my friends and family who helped me along the way of completing this thesis.

Abstract

A design process of a new building is becoming increasingly complex which makes it difficult to implement sustainability assessment during a building process of a new building. By modeling an existing business process using IPD with Petri nets, and extending this business process with sustainability assessment, this paper analyzes the impact of sustainability assessment on the design process of a new building. A Petri net is a mathematical modeling language that can be used to describe the behavior of a business process with many components and parts. Integrated Project Delivery (IPD) is a method of project delivery distinguished by a contractual arrangement among a minimum of owner, constructor and design professional that aligns business interests of all parties. IPD motivates collaboration throughout the design and construction process, tying stakeholder success to project success, and embodies the following contractual and behavioral principles.

To reach this goal my research is divided in four parts: investigating the IPD method at Vibes building engineering and modeling it into a Petri net, validation of the IPD model, investigating Breeam.nl and incorporating this assessment method with the existing IPD model into a new model, and finally, analyzing and comparing the two models. This resulted in a comprehensible model which maps an IPD process for a company like Vibes building engineers. The analysis of the model shows a significant increase in complexity of the IPD process when the sustainability assessment method Breaam.nl is added to an IPD design process of a new building.

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Introduction

Nowadays, it has become common practice to assess the sustainability of new buildings during the design process. This trend started after evidence appeared concerning the impact of buildings on the environment. An example of this evidence is the fact that 40% of the global carbon emissions are caused by buildings (Schlueter & Thessling, 2009). Governments all over the world initiated different kinds of assessment methods to guide new legislation regarding sustainability. Frequently used assessment methods in the world are Leadership in Energy and Environmental Design (LEED), the Building Research Establishment Environmental Assessment Method (BREEAM), CASBEE, SBTool and Green Globes. (Motawaa & Carter, 2013). In the Netherlands only two methods are being used that cover all aspects of sustainability according to research from the Royal Institution of Chartered Surveyors, RICS (2013). These two methods are BREEAM (specified tot the Dutch market as Breeam.nl) and LEED. Of these two methods Breeam.nl has been used most often, 138 certificates and pre-certificates have been granted in the period 2012/2013 to only 1 LEED Project over the same period (RICS, 2013).

Recent developments introduced new tools improving the application of sustainability assessment of new buildings. Building Information Modeling (BIM) allows for multi-disciplinary information to be processed through one model, thereby creating an opportunity for sustainability measures to be incorporated throughout the design process (Autodesk 2008). BIM is an integrated process built on coordinated, reliable information about a project from design through construction and into operations. By adopting BIM, architects, engineers, contractors and owners can easily create coordinated, digital design information and documentation. This information is used to accurately visualize, simulate, and analyze performance, appearance and cost and reliably deliver the project faster, more economically and with reduced environmental impact. (Autodesk 2008).

An example of BIM integrated with sustainability assessment is examined by Jrade A and Jalaei F (2013). In this case BIM was integrated with sustainability assessment to be able to assess new buildings in the concept phase of the design process. This model consists of 4 phases and combines BIM, sustainability, Life Cycle Analysis (LCA) and the sustainability assessment method (Jrade A, Jalaei F, 2013).

To be able to apply BIM in a design process, it is necessary to implement a suitable delivery method. (Asmar et al, 2013) indicate Integrated Project Delivery method (IPD) most suitable as a delivery method to be used in present day building projects. Asmar et al, investigated 35 recently finished building projects and divided them between IPD and non-IPD- methods. Projects delivered by IPD performed with the best results based on nine performance areas.

In current literature IPD and BIM present solid resources to integrate sustainability assessment in the design process of a new building. However, it remains unclear what influence the sustainability assessment has on the design process of a new building itself while using tools like BIM.

By modeling an existing business process using IPD and extending this business process with sustainability assessment, I intend to analyze the impact of sustainability assessment on the design process of a new building. These two business processes will be designed as Petri nets.

A Petri net is a mathematical modeling language that can be used to describe the behavior of a business process with many components and parts (van der Aalst & Stahl, 2011). The advantages of Petri net to model the design process of a new building project are (van der Aalst & Stahl, 2011):

- A Petri net has a mathematical foundation, which allows a researcher to apply various analysis techniques.
- Petri nets offer a formal but also graphical notation and are, therefore accessible for non-experts.
- A Petri net model is easily modified to represent different situations within a business process.
- A variety of software is available to model the behavior of business processes with Petri nets.

By modeling an existing business process using IPD with Petri nets, and extending this business process with sustainability assessment, I intend to analyze the impact of sustainability assessment on the design process of a new building.

Point of departure

To accomplish the research goal, current knowledge about the most relevant topics has to be obtained first to establish a foundation for the research. First, the current knowledge regarding integrated project delivery method will be presented to give insight to the business process based on IPD we intend to investigate. Next, more details will be delivered about the sustainability assessment method, Breeam.nl, which will be applied as the sustainability assessment method, mentioned in the research goal. Breaam.nl is has been chosen for this research because it's used most often in the Netherlands as sustainability assessment during the design of buildings, (RICS 2013).
Finally, more detailed information about Petri nets will be presented. Petri nets have been chosen to model the IPD process because their accessibility for non-experts and the various analysis techniques they provide.

Integrated Project Delivery

A project delivery method is a system used by an agency or owner for organizing and financing design, construction, operations, and maintenance services for a structure or facility by entering into legal agreements with one or more entities or parties (Wikipedia 2014).

Most of the new buildings are still conducted with the so called "traditional" project delivery method normally called Design-Bid-Build (DBB). Participants in this method are the owner, architect, and contractor with traditionally separate contracts. Normally this method involves competitively bid, lump sum construction contracts based on complete and prescriptive contract documents

prepared by architects. These documents generally include drawings, specifications, and supporting information. In general the work phases are conducted in linear sequence: the owner contracts with an architect for design, uses the design documents produced by the architect to secure competitive bids from contractors and, based on an accepted bid, contracts a contractor to construct the building (AIA 2011).

Integrated project delivery is substantially different compared to DBB. According to the AIA/AIAA: "IPD is a method of project delivery distinguished by a contractual arrangement among a minimum of owner, constructor and design professional that aligns business interests of all parties. IPD motivates collaboration throughout the design and construction process, tying stakeholder success to project success, and embodies the following contractual and behavioral principles" (AIA, 2010).

The contractual principles are:

- Key participants bound together as equals.
- Shared financial risk and reward based on project outcome.
- Liability waivers between key participants.
- Fiscal transparency between key participants.
- Early involvement of key participants.
- Jointly Developed Project target criteria.
- Collaborative Decision Making.

The behavioral principles are:

- Mutual respect and trust.
- Willingness to collaborate.
- Open communication.

(AIA/AIACC, 2010)

By implementing an integrated project, a building project starting from conceptualization and to finishing a project is significantly different for a non integrated project:

- Moving design decisions upstream as far as possible to where they are more effective and less costly suggests a re-thinking of typical project phases.
- Integration of early input from constructors, installers, fabricators and suppliers as well as from designers during the design process: this integration often is the result of modeling and simulating the project accurately using BIM tools.

These two concepts enable the design to elevate to a much higher level of completion before the documentation phase is started. These concepts take effect in the IPD process phases called Conceptualization, Criteria Design, and Detailed Design. During theses phases all participants will have to show more involvement and effort than in a traditional flow of the design phase.

This higher level of completion in earlier project stages means that the next phase, Implementation Documents, requires less effort than the traditional Construction Documents phase, and the early participation of regulatory agencies, trade contractors, and fabricators allows shortening of the fifth and sixth phases, Agency Review and Buyout, as well. The IPD phases conclude at project Closeout (AIA 2007).

Breeam.nl

BREEAM (Building Research Establishment's Environmental Assessment Method) has been developed by the Centre for Sustainable Construction, part of the Building Research Establishment (BRE) in 1990. A BREEAM assessment uses performance indicators, to evaluate a building's specification, design, construction and use. These indicators represent nine categories and criteria from energy to ecology. They include aspects related to energy and water use, the internal environment (health and well-being), pollution, transport, materials, waste, ecology and

management processes. The BREEAM performance indicators are called credits and, for each credit, a certain amount of points can be acquired. These points can be obtained per category and through qualitative weighting a total score is obtained. Within bandwidths the total score of the examined building receives a qualification on the certificate: Pass, Good, Very Good, Excellent or Outstanding.

The goal of the BREEAM assessment is:

- Market recognition for low environmental impact buildings.
- Confidence that tried and tested environmental practice is incorporated in the building.
- Inspiration to find innovative solutions that minimize the environmental impact.
- A benchmark that is higher than regulation.
- A system to help reduce running costs, improve working and living environments.
- A standard that demonstrates progress towards corporate and organizational environmental objective (Breeam.nl homepage).

Breeam.nl is based on BREEAM-international standard which was translated into Dutch and adjusted to Dutch standards by the Dutch Green Building Council (DGBC).

During the design phase of a new building, only a temporary Breeam.nl certificate can be issued for a new building project. The final certificate can only be issued after a Breeam.nl rapport of the assessor is evaluated by the DGBC, after the building is finished.

Petri nets

The basic concept behind a Petri net is developed by Carl Adam Petri (1962-2010). Other developers extended the concept with new additions over time to facilitate more complex business processes. Displayed below is a simple Petri net model of an elevator:

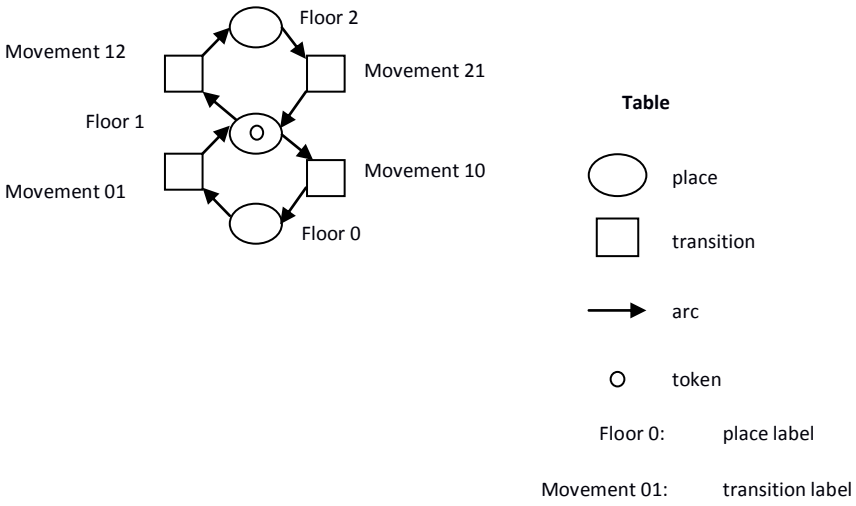

Figure 1, Example of an elevator as a Petri net (derived from: Modeling Business Processes, a Petrinet Oriented Approach)

In the table of the figure displayed above, graphical shapes correspond with Petri net characteristics. "Tokens" are used to express the dynamics of the system and are situated in the circles, called places, of the Petri net model. Transitions are the active components of the system, places and tokens themselves are passive. A transition can only be executed when every "input" place contains a token.

If the Elevator, displayed in the figure above, moves from floor 1 (it's current position, displayed by the token) to floor 2, the toke itself will move too, via movement12 to place "floor2". This movement is called the "firing" of a transition. In other words, moving the elevator from floor 1 to floor 2 will fire transition movement12. The arcs inside the Petri net model represent the direction of the change.

In general:

- A current state of a process is modeled in a Petri net as a token in a designated place.
- Changes from one state to another, are modeled by transitions.
- Tokens often represent object (people, goods, machines), informative, object, current situation of an object.
- Places represent blockades, channels, geographic locations, conditions or a state.
- Transitions represent events, transformations or transportations.

Mathematically, a Petri net is a bipartite graph. A graph consists of a collection of points, called nodes and lines or arcs. A bipartite graph is a graph whose vertices can be divided into two disjoint sets U and V (that is, U and V are each independent sets) such that every edge connects a vertex in U to one in V. Equivalently, a bipartite graph is a graph that does not contain any odd-length cycles. (Wikipedia, 2014).Displayed below is a example of an bipartite graph (Wikipedia 2014):

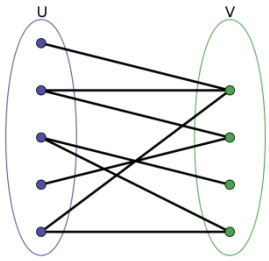

Figure 2, graphical representation of a bipartite graph

Petri net extensions

When very complex business processes need to be modeled, a normal Petri net has to be extended to a high level Petri net. Most important extensions to a basic Petri net are the extensions called "color", "time", and "hierarchy" (van der Aalst & Stahl, 2011).

Hierarchy makes it possible to display a simpler overview of a complex Petri net model. A square, representing a transition in a Petri net model, is supplemented a text frame beneath, which describes the name of the square:  . This figure is called a module and stands for a black box representing a complex Petri net process. The portion of the total Petri net depicted as a module in a

Petri net model is called a subnet. Consequently, a subnet can have its own modules. These modules of subnet are called sub-subnets of the original Petri net.

The extension color facilitates a token in a Petri net model to change color. These kinds of Petri nets are called "*colored Petri nets*" (van der Aalst & Stahl, 2011). Different values can be added to token in a colored Petri net.

Lastly, the extension time makes a token available in a Petri net after a certain amount of time. With this extension a token is able to receive a "time stamp". A token with a time stamp isn't available until a certain amount of time delay is reached. With this extension, the run time of token can be influenced.

State space

The state space of a Petri net contains all possible situations within a business process. Like in the previous Petri net model of an elevator displayed in figure 1, the state space of our example are the possible floors the elevator can reach. For a Petri net model the state spaces can described as all possible situations tokens of a Petri net can be distributed in the Petri net between all its transitions. Just one possible distribution of a token like shown in the Petri net elevator model is called a marking. All possible markings define the state space of a Petri net. Those possible markings can be represented by a reachability graph which serves as a tool for verifying various Petri net properties.

Research method

As mentioned earlier, the goal of my research is modeling an existing business process using IPD with Petri nets, and extending this business process with sustainability assessment to analyze the impact of sustainability assessment on the design process of a new building.

To reach this goal my research, I divided my research in four steps before I started with the research. These four steps were:

1. Investigating the IPD method at Vibes building engineering and modeling it into a Petri net with the software program CPN Tools.
2. Validation of the IPD model.
3. Investigating Breeam.nl and incorporating this assessment method with the existing IPD model into a new model.
4. Analyzing and comparing the two models.

My research method will be explained next divided between the four steps:

Investigating the IPD method

First, the IPD design process in use at Vibes building engineers was investigated. Vibes building engineers is a company providing design, engineering, consulting and management to realize and manage of buildings by means of an integrated approach and cooperation. Investigation of the IPD design process did start by examining the IPD agreement. A literature study was conducted about the agreement, a back ground investigation and interviews were held with J.K. Pikkaart, the Vibes general manager who realized the agreement.

Next the literature study continued with investigating IPD design process. Indentifying the tasks performed during the design process of a new building was done with “Standaard taakbeschrijving (DNR-STB), 2009” issued by BNA/ONRI in 2009. In this document all process tasks are documented required for realizing a new building by Dutch requirements. Another interview was held with J.K. Pikkaart to ascertain Vibes opinion of the tasks outlined in the “Standaard taakbeschrijving”. As a result, a list of tasks was indentified containing tasks to be performed to execute a design process of a new building with the IPD method.

With the main conditions of the IPD agreement acquired, design phases indentified and the tasks per design phase catalogued, this knowledge is now transformed into an information system model with the help of Petri Nets. A literature study about Petri nets was conducted with the help of the book “modeling business process”.

In the first version of the model most of the IPD design tasks were transformed into transitions if these tasks represented actions within the process that changed a current state of the IPD process. Tasks that could represented as documents needed during the IPD process were transformed into places of the Petri net. The places and transitions were given names corresponding IPD process tasks/documents they represent in the Petri net as clarification. The interactions between these transition-tasks and place-tasks were represented by arcs. This first version of the Petri net was modeled with CPN tools. After verification the Petri net the internal consistency was inadequate and a higher abstraction level was applied. This resulted in a Petri net with less places, transitions and arcs and the internal consistency of the model was improved.

Validation of the IPD model

Validation of a model normally consists of checking whether correctly reflects what it intends to do. This IPD Petri net intended to represent a comprehensible model for Vibes employers. From Vibes’ perspective, the goal of the Petri net model was to display a comprehensible workflow model of the IPD method. After the initial model was setup, the model was validated with help J.K. Pikkaart, general manager and H Bonsma, chief project manager at Vibes. Validating the model started with a meeting to indentify the requirements of the model. After three more revisions of the model, a final, fourth version was realized complying with the major requirements as identified by Vibes.

Validation of the Petri net model can be summarized as followed:

- Dividing all IPD process tasks into a hierarchal Petri net with five subnets confirming with the five IPD phases into a minimum amount of transitions and places to represent the critical tasks of the IPD process.
- Detailed validation of each subnet separately.
- Validating the sequencing of transitions and places in each subnet.

Investigating Breeam.nl

Documentation provided by the DGBC about Breeam.nl provided the core for the investigation about Breeam.nl. This documentation provided information regarding the required tasks to be performed for acquiring the desired credits in accordance with the targeted Breeam.nl qualification. Besides these documents, a Breeam.nl expert, Michel Kemper employed at Lomans Installatie Techniek, was interviewed. A Breeam.nl expert has received had training by the DGBC about the basic concepts regarding Breeam.nl. This interview helped acquiring knowledge about applying Breeam.nl during the design process of a new building project. The required Breeam.nl tasks were integrated into the existing IPD model. Management tasks crucial or executing Breeam.nl were also integrated. With this information the existing IPD- Petri net model was developed into a second model with the Breeam.nl assessment method incorporated.

Analyzing and comparing the two models.

Finally the two models were analyzed and compared to each other to fulfill the research goal. With the help of CPN tools both models were analyzed by their Petri net characteristics. Analysis of the Petri net during the design analysis consists of reachability analysis and analyzing the fairness of the two Petri nets.

Reachability analysis

Reachability analysis is a common verification technique to explore the state space of a model. Reachability analysis investigates the state space of a Petri net. The state space of a Petri net is defined by the reachability graph of the Petri net. The amount of arcs and nodes of a reachability graph indicate all markings of a Petri net, therefore the amount of arcs and nodes represent an indication of complexity of a Petri net provided the reachability graph is finite.

Fairness analysis

Fairness is an indicator for transitions of a Petri net. It detects a sequence of transitions within a Petri net that can repeat itself infinitely often. This occurs in a Petri net when a certain decision has to be made as nondeterministic choice between two transitions. To detect a so called infinite run in a Petri net, four notions of fairness are defined to describe transitions in a Petri net;

1. Impartial: an impartial transition occurs infinitely often in every infinitely run of the Petri net.
2. Fair: a fair transition occurs infinitely often in every infinitely run of the Petri net where it is enabled infinitely often.
3. Just: a just transitions occurs infinitely often in every infinitely run of the Petri net where it is continuously enabled form a marking onward.
4. Not Fair: a Not Fair transition if and only it is not just: there is an infinite run in the Petri net that enable it from a marking onward and does not fire anymore.(van der Aalst & Stahl, 2011).

With fairness those transitions can be detected that cannot fire infinitely often while being enabled infinitely often. It also shows how many transitions are affected by infinite runs of a Petri net and in which degree. Concerning the two modeled Petri nets, these transactions affected by fairness have more influence in the total run of the Petri nets since they potentially can influence the modeled

business process multiple times. Fairness analysis therefore is used in the research to analyze the amount of transitions that have more influence on the Petri nets than normal transitions.

Research data

Results

In this chapter the construction of the IPD design process will be explained in detail. The development of the Petri net model and its validation process are explained thereafter.

Investigating IPD

Background IPD process

The integrated project delivery process currently in use at Vibes Building engineers is formalized in the IPD agreement devised by Vibes building engineers themselves. The Vibes IPD agreement is based on the standard IPD agreement devised by the company Hanson Bridget and adapted to the requirements of Vibes. “The Hanson Bridgett IPD model is a multi-party agreement that seeks to succinctly state IPD principles within a readable and logical agreement (Hanson Bridgett 2010).The agreement of Hanson Bridget is based on the article “Integrated Product Delivery: A Guide” published in 2007 by the American institute of Architects and Hanson Bridgett’s experience and involvement in actual IPD projects (Hanson Bridgett 2010).

The content of the Vibes IPD agreement is similar to the Hanson Bridget agreement. The main conditions in both agreements concern:

- How project decisions are made.
- How and when the project target cost is set.
- How compensation and incentives are structured.
- How changes in the work and contingency are addressed.
- Risk allocation, including insurance, indemnity, and limitation of liability.

- Transparency and access to project documents and records.
- Dispute resolution procedures.

The main conditions of the IPD agreement that determine the structure of the IPD process are:

- How project decisions are made

Project decisions are made by the Project Management Team (“PMT”), which includes a representative for the Owner, Architect and Contractor. Decisions by the PMT must be unanimous. PMT decisions affecting design, cost, schedule or reallocation of the Work are confirmed through a PMT Directive. There is also a Project Implementation Team (“PIT”), which includes the PMT representatives and consultants, design-build subcontractors and others who may have a significant impact on the project outcome. The PMT actively seeks and considers input from the PIT.

- How and when the project targets are set

Validated Target Cost, abbreviated for the Vibes IPD process as VDK, is set during the Conceptualization Phase. The VDK represents the costs according PMT deems sufficient to design and construct the project in accordance with the Validated Target Program (“VDP”) and within the Validated Target Schedule (“VDT”).

The VDK, VDP, VDT are part of the Project Objective (“Project Doel stelling, PDS”), which must be unanimously adopted by the PMT during the Conceptualization Phase.

The IPD agreement made by Vibes divides all terms to which the participants agree into five different phases. These five phases in the Vibes IPD process are: “initiatie” phase (conceptualization), “project definitie” phase (criteria design), “scenario studie” phase (detailed design), “technisch ontwerp” phase (implementation documents) and “productie voorbereiding” phase (agency review and buyout). Theme’s represent a group of tasks with similarly features and have to be executed in every phase.

The function of the five design phases can be described as followed:

1. “initiatie” phase (conceptualization): what, who how will the project be built?
2. “project definitie” phase (criteria design): a general description of the project will be defined and multiple options are examined.
3. “scenario studie” phase (detailed design): The question “what” to build is specified and answered. In BIM terms, level of development (LOD) of 200 will be reached as a BIM model
4. “technisch ontwerp” phase (implementation documents): documentation about “how” the project will be built should be nearly finished and the BIM model will reach LOD 300.
5. “productie voorbereiding” phase (agency review and buyout): The momentum of “what” to build will shift to “how” to build.

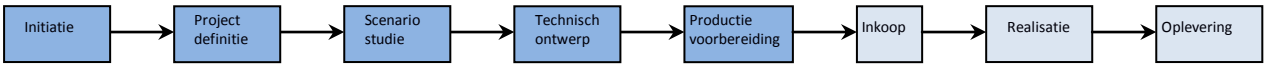

Figure 3, phases of the IPD process, darker colored phases are part of the design phase.

IPD design tasks

Besides the IPD agreement, the IPD Process is influenced by general design tasks that have to be performed to realize the design of a new building. These tasks, regulated by Dutch law, are described in the “ Standaard taakbeschrijving (DNR-STB), 2009” issued by BNA/ONRI in 2009. In this document the design process of a building is split in all possible tasks deemed possible to successfully execute a design process. About 2000 possible tasks are described divided into eight design phases. These tasks are categorized between “critical” and “non critical” tasks. The total amount of critical tasks contains the minimum requirements for a responsible construction design. Non critical tasks are possibly performed depending on the building project specifically.

Furthermore, all tasks are categorized into three themes:

1. Owner/client theme: all tasks concerning decision making and support from advisors
2. Design theme; all tasks concerning design process of the construction and it's direct environment
3. Project management theme; all management tasks concerning the design process, these tasks are meant to guide the design project towards its goal.

This DNR-STB list was transformed to a list of tasks that are needed to realize a new building designed with the IPD process. The total amount of tasks was reduced during this transformation because less project management related tasks are needed by reducing the amount of phases. The list of tasks concerning decision making could also be reduced.

Table 1 and table 2 show the reduction in design phases as a result of transforming the DNR-STB list to the IPD process and the reduction of total amount of tasks that are necessary to realize a new building.

Design phases DNR/STB	initiatie	Project definitie	Structuur ontwerp	Voor ontwerp	Definitief ontwerp	Technisch ontwerp	Uitvoerings gereed ontwerp	Inkoop
No. tasks DNR/STB (total 792)	60	49	78	121	141	158	79	106

Table 1, all tasks concerning the DNR/STB task list during the design process

Design phases IPD	initiatie	Project definitie	Scenario studie	Technisch ontwerp	Productie voorbereiding
No. tasks IPD (total 565)	60	52	138	209	106

Table 2, all tasks concerning the IPD design Process

Appendix A shows the tasks of the Project definition phase as an example of the task list per design phase of the IPD process. This example contains the tasks necessary to design a new building according to DNR_STB list supplemented with tasks necessary to fulfill the conditions of the IPD agreement during the project definition phase.

IPD Petri net model and validation of the Petri net

In the chapter research method the development of the Petri net during verification and performance analysis has been explained. This resulted in one Petri net model before final verification of the model and one afterwards, which was used for validation. After validation with Vibes' employees, four more models were produced until the final one fulfilled the requirements. To show the transformation of the Petri net during its design process, the changes in the sub net project definition during verification and validation of the Petri net is shown in Table 3 below.

	Before verification	After verification	Validation Version 1	Validation Version 2	Validation Version 3	Final Version
Subnet project definieren						
Places	39	10	9	19	19	18
Transitions	18	5	5	11	11	11
Arcs	98	23	20	44	42	43
Sub-subnet voortgangs rapportage						
Places	11					
Transitions	12					
Arcs	27					
Sub-subnet uitvoerings Taken						
Places	4					
Transitions	2					
Arcs	11					
Subnet contracteren onderaannemers						
Places		11				
Transitions		12				
Arcs		27				
Subnet toetsen project doelstelling						
Places		4	4			
Transitions		2	4			
Arcs		13	19			

Table 3, transformation of the subnet project definition during verification and validation of the Petri net model

The final Petri net model with its five modules is shown is below:

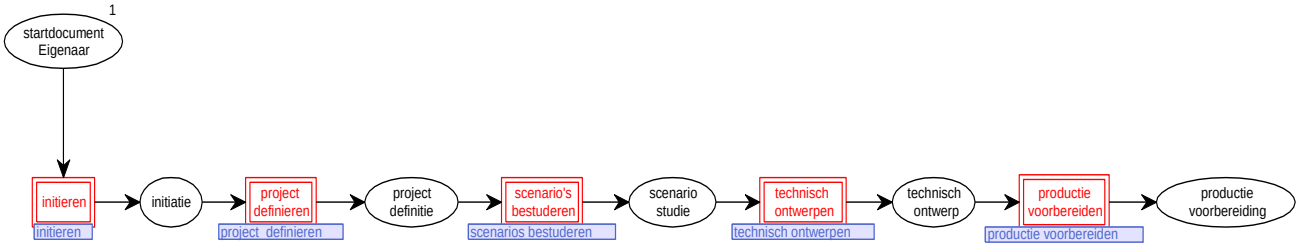

Figure 4, hierarchal Petri net model, with all 5 design phases modeled as modules.

The final version of each subnet of the five modules can be found in Appendix B.

Investigating and incorporating Breeam.nl

Executing the Breaam.nl assessment during the design process of a new building adds extra tasks to be performed during the IPD process. These tasks are described in the document *Beoordelingsrichtlijn Nieuwbouw* (DGBC 2011). After indentifying the Breeam.nl tasks, these tasks were divided between the five IPD process phases. This resulted in a new IPD business process model with Breeam.nl tasks incorporated. The same procedure was used for creating the second Petri net model as was used for the first Petri net model. Only one evaluation was necessary to discuss new Petri net model. In the table on the next page, the differences in places, transitions and arcs are shown.

	IPD proces model	IPD Model with Breeam
Subnet initieren		
Places	13	14
transistions	7	8
arcs	29	31
Sub-subnet contracteren		
Places	3	3
transitions	5	5
arcs	11	11
Subnet project definieren		
Places	18	18
transitions	11	11
arcs	43	43
Subnet scenario's bestuderen		
Places	12	14
transitions	11	12
arcs	30	34
Subnet technisch ontwerpen		
Places	16	18
transitions	13	13
arcs	38	42
Subnet productie voorbereiden		
Places	15	18
transitions	12	14
arcs	35	44

Table 4, distribution of places, transitions and arcs of the two Petri net models.

The final version of each subnet of the Petri net model altered by Breeam.nl incorporated can be found in appendix C.

Research Analysis

The goal of this investigation is to compare a design process with and without sustainability assessment. Both models of these processes were designed to comply with the properties of a Petri net and the by specifications given of the end user, Vibes building engineers. To compare these two Petri nets both models the models were analyzed for reachability and their fairness properties

Reachability comparison

Reachability analysis was done with CNP tools. Table 3 below show the reachability properties of both models.

	Petri net model	Petri net model with Breeam.nl
No. arcs	188	207
No. transitions	59	64
No. places	90	100
State space: nodes	76	90
State space: arcs	145	170

Table 5, distribution of places, transitions and arcs between two Petri net models.

Despite the few extra added transitions, places and arcs the reachability graph is increased significantly with both 18% more nodes and arcs. This indicates adding Breaam.nl to the IPD process will have a significant impact on the IPD business process, since the state space of the extended model is significantly larger than the state space of the original model.

Fairness comparison

In table 4 below, the transitions are shown with the four different notions of fairness.

	Petri net model	Petri net model With Breeam.nl
Impartial transitions	0	0
Fair transitions	16	16
Just transitions	0	0
Not Fair transitions	41	46

Table 6, fairness transitions

With the addition of Breeam.nl to IPD process, the Petri net is increased with 5 more transitions affected by fairness, indicating more influence of infinite runs on the transitions of the Petri net with Breeam.nl. These transitions are “Breeam_credits_bepalen” from subnet “scenario’s bestuderen”,

“Breeam_credits_bepalen” from subnet “technisch ontwerpen”, 'Breeam_Specificaties” and “Controleren_Breeam_Rapport_door_Assessor “from the subnet ”productie voorbereiden (see appendix C).

This increase is caused by three extra infinite runs that are caused by the addition of Breeam.nl to the existing Petri net model of the IPD process. The subnets scenario studie (detailed design), technisch ontwerp (implentation documents) and product voorbereiding (agency review and buyout), each gain an extra infinite run. ”. The fifth transition ”BREEAM_credtis_bepalen_aan_de_hand_van_streefkwalificatie_en_budget” from subnet initiëren , marked as not fair by the fairness analysis is not part of an infinite run with any consequence to the IPD process.

Conclusions and recommendations

After modeling the IPD process into a Petri net and extending this Petri net model with the sustainability assessment Breeam.nl, it was possible to analyze the impact of sustainability assessment on the IPD design process of a new building. Using analysis techniques specified for Petri nets, the extension of the Petri net resulted in a significant increase of complexity of the Petri net while both Petri nets had a similar amount of transitions, places and arcs.

If we translate this result to the IPD design process, the conclusion is that although the amount of tasks needed to execute the Breeam.nl are small, compared to the total amount of tasks to be performed during the design process of new building, the impact of the Breeam.nl assessment will be significant. This significant impact will especially be notable during the detailed design phase, the implementation documents phase and agency review and buyout phase of the IPD design process.

This research further shows the possibility of analyzing two Petri nets. In making two models of an IPD process with and without sustainability assessment, the impact of such assessment can be clearly indentified in the Petri net. Notable results were:

- With a Petri net a comprehensible model can devised which helps to map an IPD process for a company like Vibes building engineers.
- A clear chain of events that occurring during the IPD process, can be identified as fairness transitions in the Petri net. These transitions gain in importance if sustainability assessment is applied in the design process. These transitions become visible thanks to their fairness properties.

Recommendations

Since the research concluded sustainability assessment may have a significant impact on the IPD design process despite its small size compared to the total design process, companies should be well aware of the impact of sustainability assessment. In general, this awareness can be realized in general by carefully integrating the Breeam.nl assessment method into the IPD process. This can be done by planning all Breeam.nl related tasks as early as possible during the design process and informing all relevant participants of the task requirements.

More specific recommendations can be concluded out of the transitions of the Petri net. As fairness analysis showed the Breeam.nl tasks represented by the “Breeam.nl” transitions have extra influence in the design phases “scenario studie” “technisch ontwerp”and “productie voorbereiding”. All participants in the IPD process should be aware these Breeam.nl tasks potentially have more influence during on these design phases than other tasks.

Theoretical contributions

- Modeling an Integrated Project delivery method.

Integrated Project Delivery is a new project delivery method in the Netherlands. This Petri net helps as a roadmap for creating other Petri net models of project delivery methods in the construction industry and provides a tool to compare those different methods in theory.

- A Petri net modeling a design process of a new building

Petri net are used to model all different kinds of business processes. The two models created in this research can be used for analyzing Petri nets in general. Especially concerning translating tasks in a business process to states and transitions in a Petri net.

Practical implications

The two Petri net models created in this research can be used for further analysis concerning:

- Investigating the design process of a new building, based upon a project delivery method other than the IPD method
- Investigating an IPD process of a new building and the sustainability assessment other than Breeam.nl
- This research can also act as a resource for other research, which investigates assessment methods in a design process of a building like cost evaluation during the design process. A Petri net model can be extended with such an assessment method besides the Breeam.nl assessment method used in this research.

Limitations and delimitations

- Some (management) tasks that have to be performed during the IPD process with sustainability assessment do not become visible in a Petri net; the extra tasks Breeam.nl

required during the project definition phase are incorporated into existing transitions and can't be modeled as separate places and/or transitions of a Petri net.

- Since the goal of this research was focused on the IPD design process and not the whole IPD (building) process, the research investigated only one part of the IPD process. Therefore, only these design phases were modeled as a Petri net and only the "Breeam.nl tasks" to be performed during the design process have been included the research.
- Using a timed Petri net model would have provided additional useful information concerning a business process (van der Aalst & Stahl, 2011). Assigning time stamps to tokens would enable the model to predict time estimates on completion of the modeled business process. This would greatly improve the usefulness of the Petri net model. The use of timed Petri net model was considered at the start of the research, but after consultation with Vibes, the use a timed Petri net was rejected due to the lack of information required to construct such a model. The time limitation set to this research was also a restricting factor.
- Both Petri net models can be classified as workflow nets, a subclass net of Petri nets (van der Aalst & Stahl, 2011). The software used for analysis in this research was CPN tools which wasn't properly equipped to verify specific properties of workflow nets. No proper tool to investigate "soundness" properties of the two Petri nets was found in CPN Tools. Soundness acts as a correctness criterion for workflow nets (van der Aalst & Stahl, 2011).

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Appendix A,

Task list of the IPD definition phase

This task list is still in Dutch and has not been translated

fase 2 project definitie

PMT

02.01 Opdrachtgeving

1. 02.01.010 N Evalueren en bijstellen beleidsuitgangspunten project
2. 02.01.020 N Nemen besluiten over faseresultaten en voortgang

02.03 Projectdoestelling

3. Opstellen Projectdoelstelling
   De Projectdoelstelling is ontwikkeld door de Partijen op basis van eisen doestellingen en beperkingen van de Eigenaar. De Projectdoelstelling bestaat uit bestaat uit het geValideerde Doel Programma (VDP), de geValideerde Doel Kosten (VDK), en de geValideerde Doel Tijdsplanning (VDT).

02.13 Organisatie/procesintegratie

4. 02.13.010 N Organiseren project
5. 02.13.020 N Sturen en bewaken project
6. Samenstellen PIT
7. Onderzoek Bouwplaats
   Het PMT zal een gezamenlijk bezoek aan de bouwplaats organiseren
8. Opstellen Projecthandboek
   Het PMT zal een projectboek maken overeenkomstig met afgesproken (IPD) contract
9. Management en Organisatie van het PMT
   Vaststellen management en organisatie middels een Kostenmanagement strategie,PMT werkplan en een BIM uitvoeringsplan
10. Kennisgeving van Impasse
    Indien de Partijen geen overeenstemming bereiken over de Projectdoelstelling, kan een partij een impasseverklaring indienen door een schriftelijke kennisgeving
11. Bonus Malus Regeling
    Vaststellen uitkeringspercentage Bonus Malus Regeling
12. Aansturen PIT

03.02 Contracten

13. Formuleren gewenste werkzaamheden aanvullende expertise (M-taak)
14. N Voorbereiden/contracteren van nieuwe leden PIT
15. N M Contracteren van nieuwe leden PIT

PIT

02.12 Geld

16. 02.12.010 N Bewaken fasebudget volgens VDK
17. 02.12.015 N C Adviseren bouwkosten per projectdeel (cluster)
18. 02.12.020 N Adviseren bouwkosten: integreren ramingen per projectdeel
19. 02.12.030 N Adviseren investeringskosten

20. 02.12.035 C Ramen exploitatiekosten per projectdeel (cluster)
21. 02.12.040 Ramen exploitatiekosten: integreren ramingen per projectdeel
22. 02.12.045 C Analyseren kosten-baten exploitatie per projectdeel (cluster)
23. 02.12.050 Analyseren kosten-baten exploitatie: integreren analyses per projectdeel
24. 02.12.055 C Inventariseren financieringsmogelijkheden per projectdeel (cluster)
25. 02.12.060 Inventariseren financieringsmogelijkheden: integreren inventarisaties per projectdeel
26. 02.12.065 C Inventariseren subsidiemogelijkheden per projectdeel (cluster)
27. 02.12.070 Inventariseren subsidiemogelijkheden: integreren inventarisaties per projectdeel

02.11 Ontwerpintegratie

28. 02.11.010 N Coördineren adviezen participanten (Partijen en PIT leden)
29. 02.11.030 Integreren toetsingen realiseerbaarheid Projectdoelstelling

02.14 Tijd

30. 02.14.010 N Plannen projectdoorlooptijd volgens VDT

02.15 Informatie en communicatie

31. 02.15.001 N Opstellen en beheren informatie- en communicatieplan fase Projectdefinitie
32. 02.15.010 N M Voeren van overleg met het PMT
33. 02.15.015 N Voorbereiden, voorzitten, verslagleggen van teamvergaderingen
34. 02.15.020 N M Deelnemen aan teamvergaderingen
35. 02.15.024 N Voorbereiden, voorzitten, verslagleggen van stuurgroepvergaderingen
36. 02.15.025 N M Deelnemen aan stuurgroepvergaderingen)
37. 02.15.030 N M Voeren van overleg met bevoegde instanties
38. 02.15.035 N M Voeren van overleg over financiering en subsidies
39. 02.15.040 N Beheren projectdocumenten

02.16 Kwaliteitszorg en risico's

40. 02.16.005 C Analyseren en behandelen projectrisico`s per projectdeel (cluster)
41. 02.16.010 Analyseren en behandelen projectrisico`s: integreren RI&E`s per projectdeel

02.17 Vergunningen

42. 02.17.010 N M Inventariseren benodigde vergunningen

02.04 Architectuur

43. 02.04.010 Toetsen realiseerbaarheid Projectdoelstelling vanuit expertise Architectuur/bouwkunde

02.05 Interieur

44. 02.05.010 Toetsen realiseerbaarheid Projectdoelstelling vanuit expertise Interieurarchitectuur

02.06Landschap

45. 02.06.010 Toetsen realiseerbaarheid Projectdoelstelling vanuit expertise Landschapsarchitectuur
46. 04.02.035 Contracteren aanvullende expertise door engineer

02.04 Bouwkunde

47. 02.04.010 Toetsen realiseerbaarheid Projectdoelstelling vanuit expertise bouwkunde

02.07 Bouwfysica en akoestiek

48. 02.07.010 Toetsen realiseerbaarheid Projectdoelstelling vanuit expertise Bouwfysica
49. 02.07.020 Toetsen realiseerbaarheid Projectdoelstelling vanuit expertise Akoestiek

02.08 Constructie

50. 02.08.010 Toetsen realiseerbaarheid Projectdoelstelling vanuit expertise Constructies

02.09 Installaties

51. 02.09.010 Toetsen realiseerbaarheid Projectdoelstelling vanuit expertise Installaties

02.10 Geotechniek

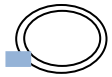
52. 02.10.010 Toetsen realiseerbaarheid Projectdoelstelling vanuit expertise Geotechniek

Appendix B,

Petri net model of the IPD design process

This appendix contains the Petri net model of the IPD model at Vibes.

Table for Petri nets

	place
	transition
	arc
	module
	Place connecting a subnet to the main Petri net

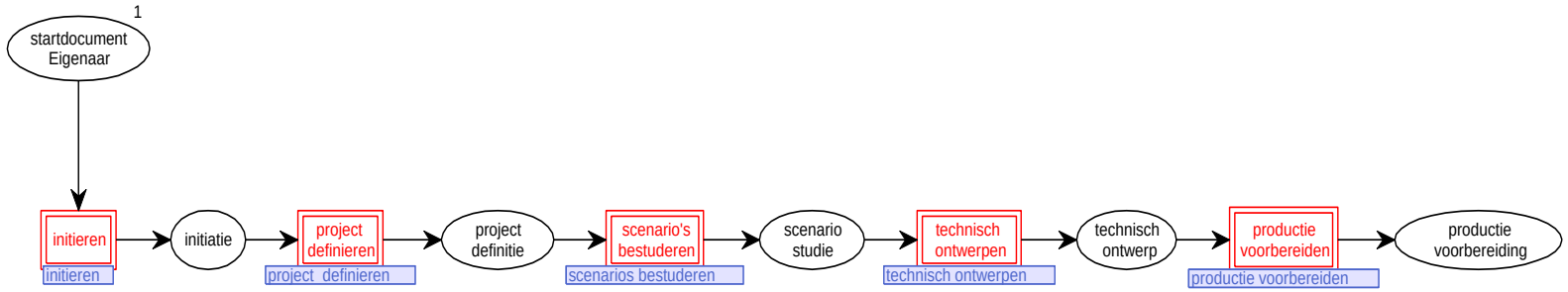


Figure3, hierarchal petri net model, with all 5 design phases modeled as modules.

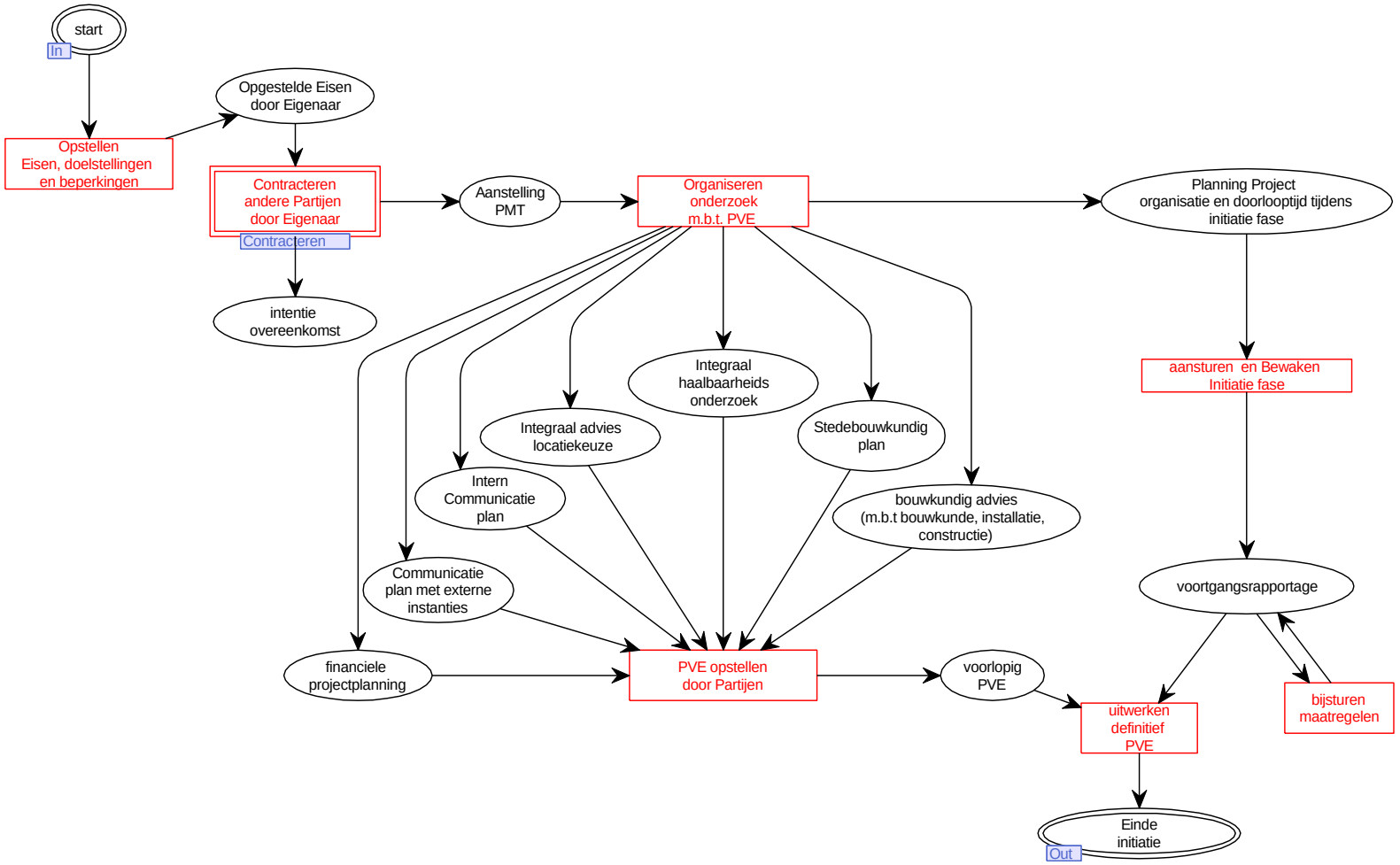


Figure 4, "initiatie" (conceptualization phase), modeled as a subnet

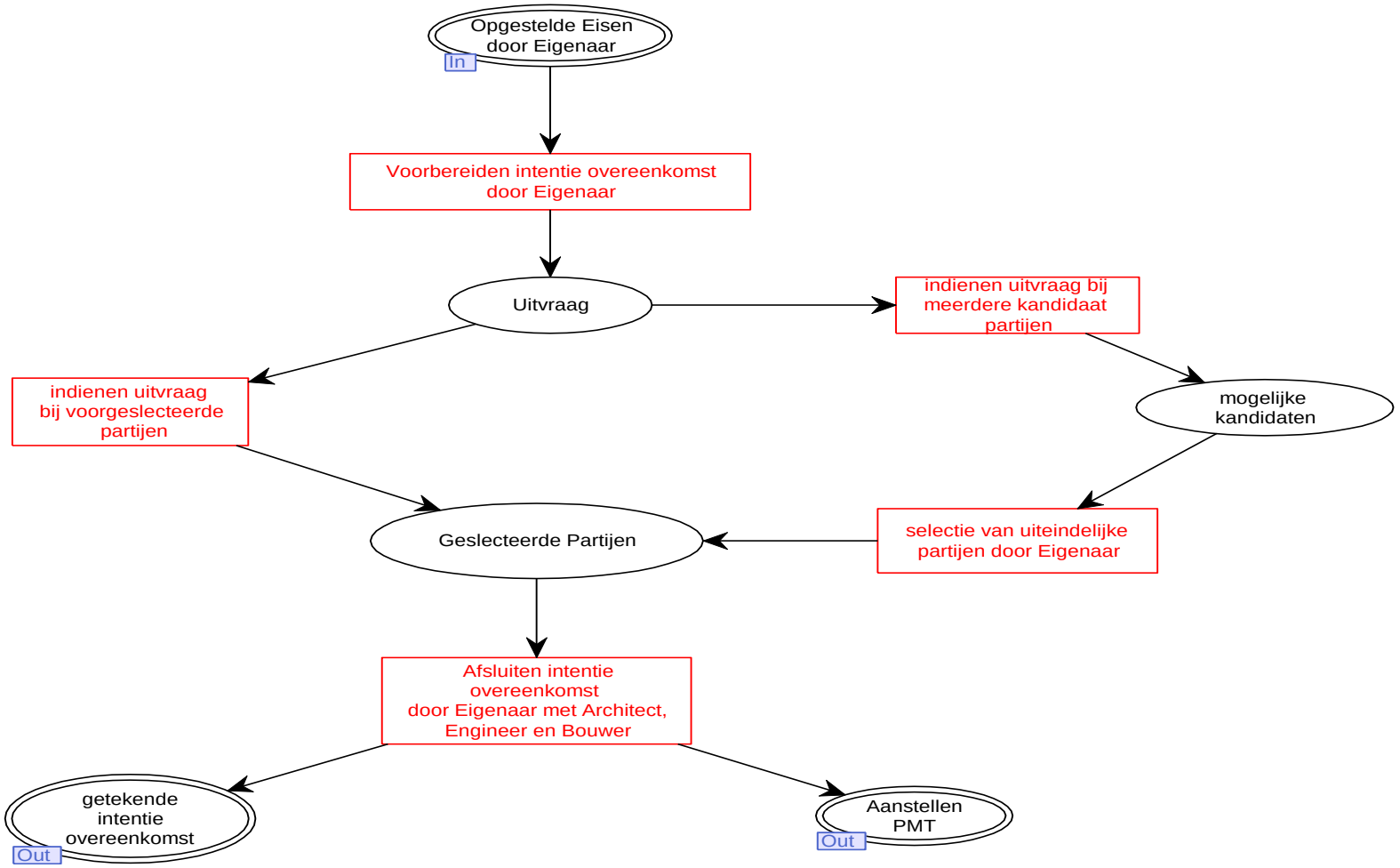


Figure 5, sub subnet " Contracteren ander partijen door eigenaar"

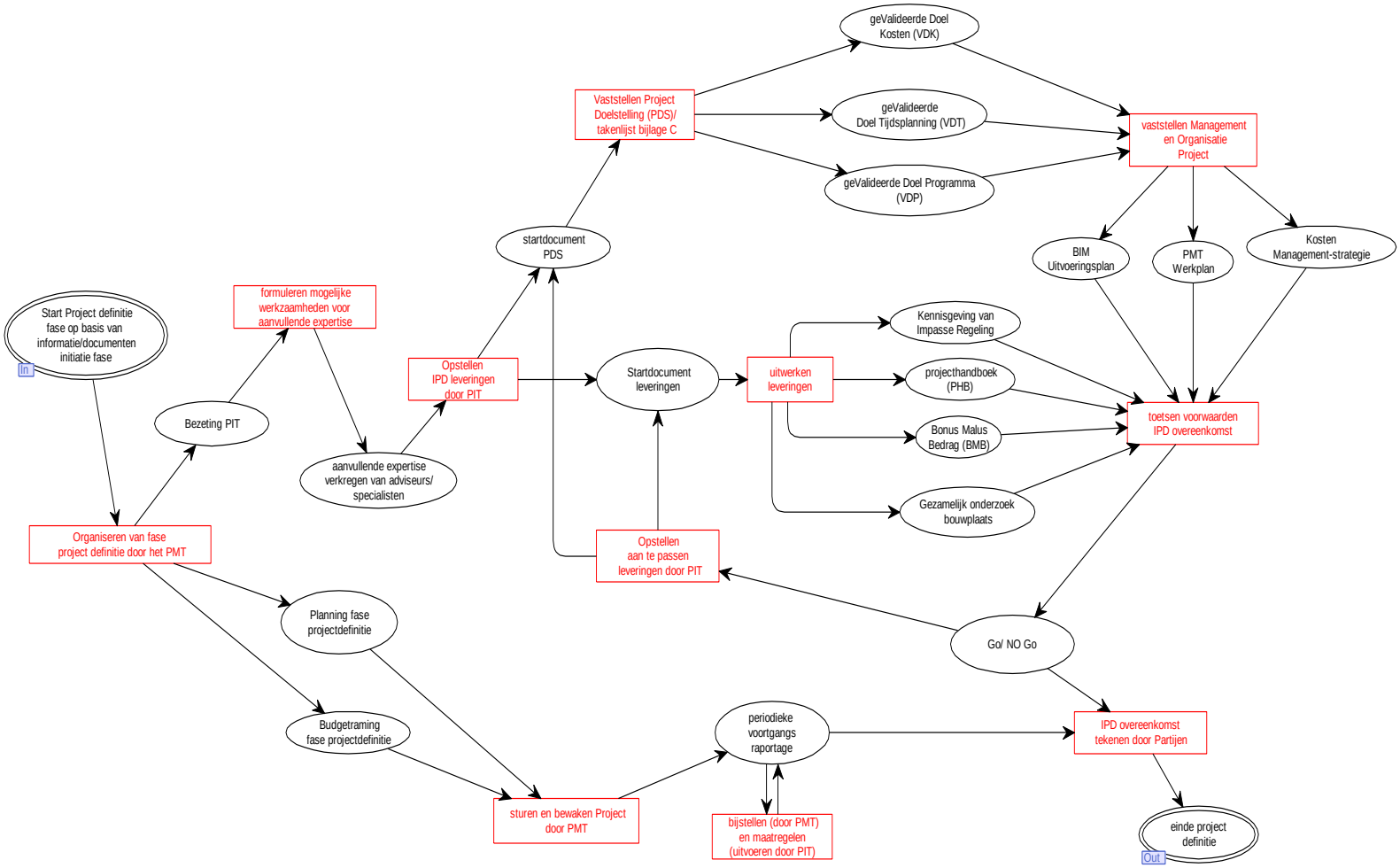


Figure 6 "project definitie "(criteria design phase) modeled as a subnet

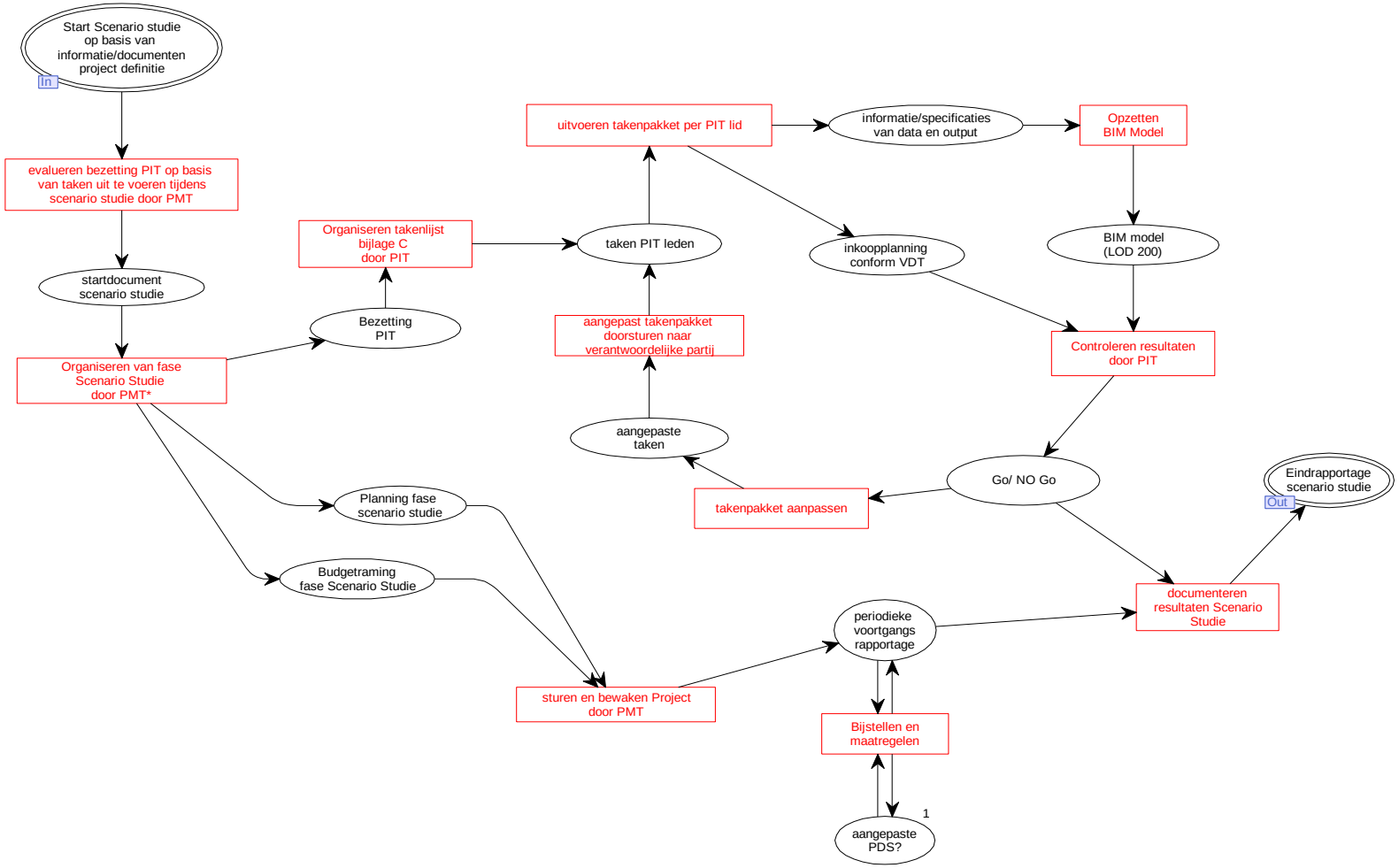


Figure 6, scenario studie (detailed design phase) modeled as a subnet

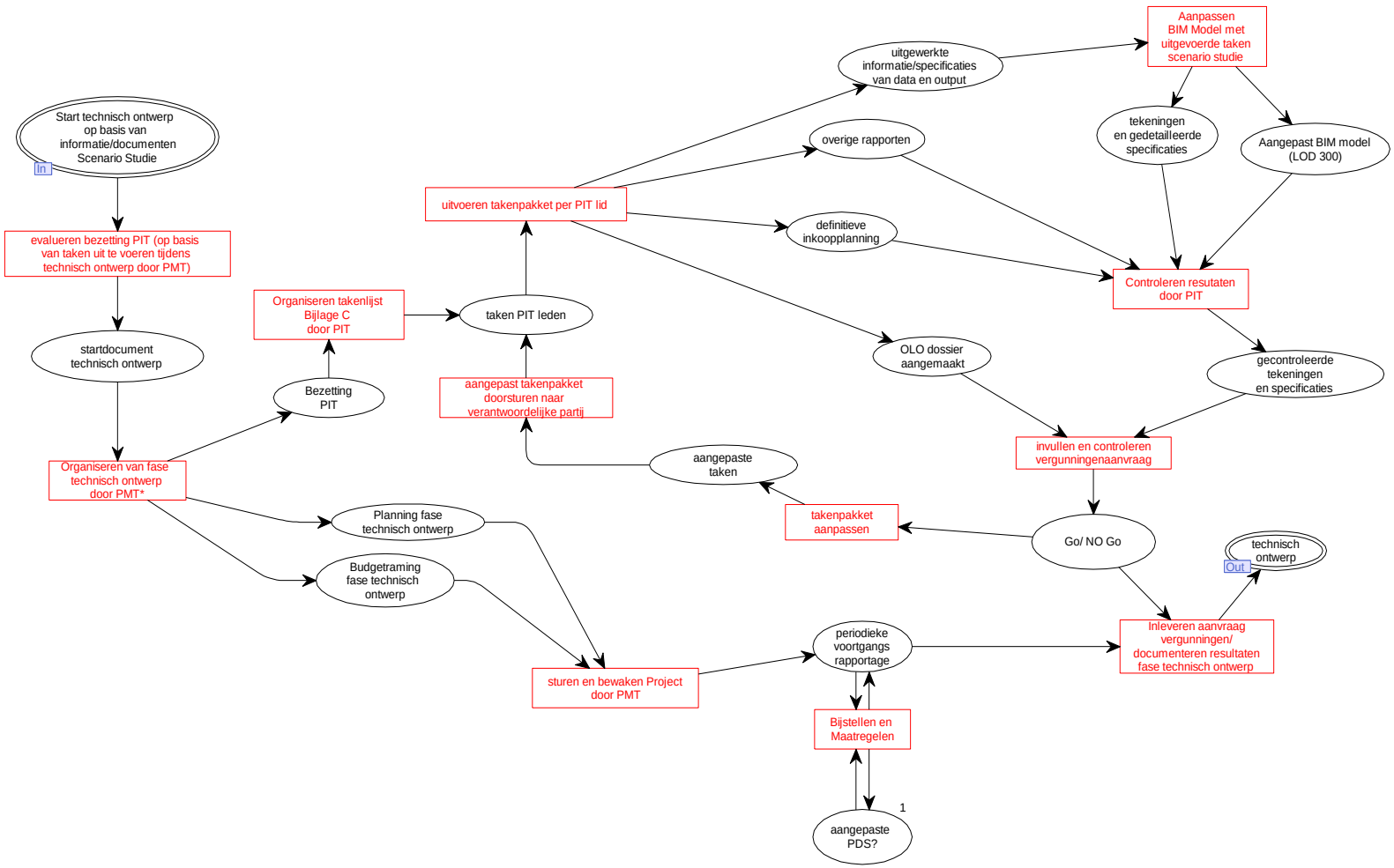


Figure 8, "Technisch ontwerp"(implementation documents phase) modeled as a subnet

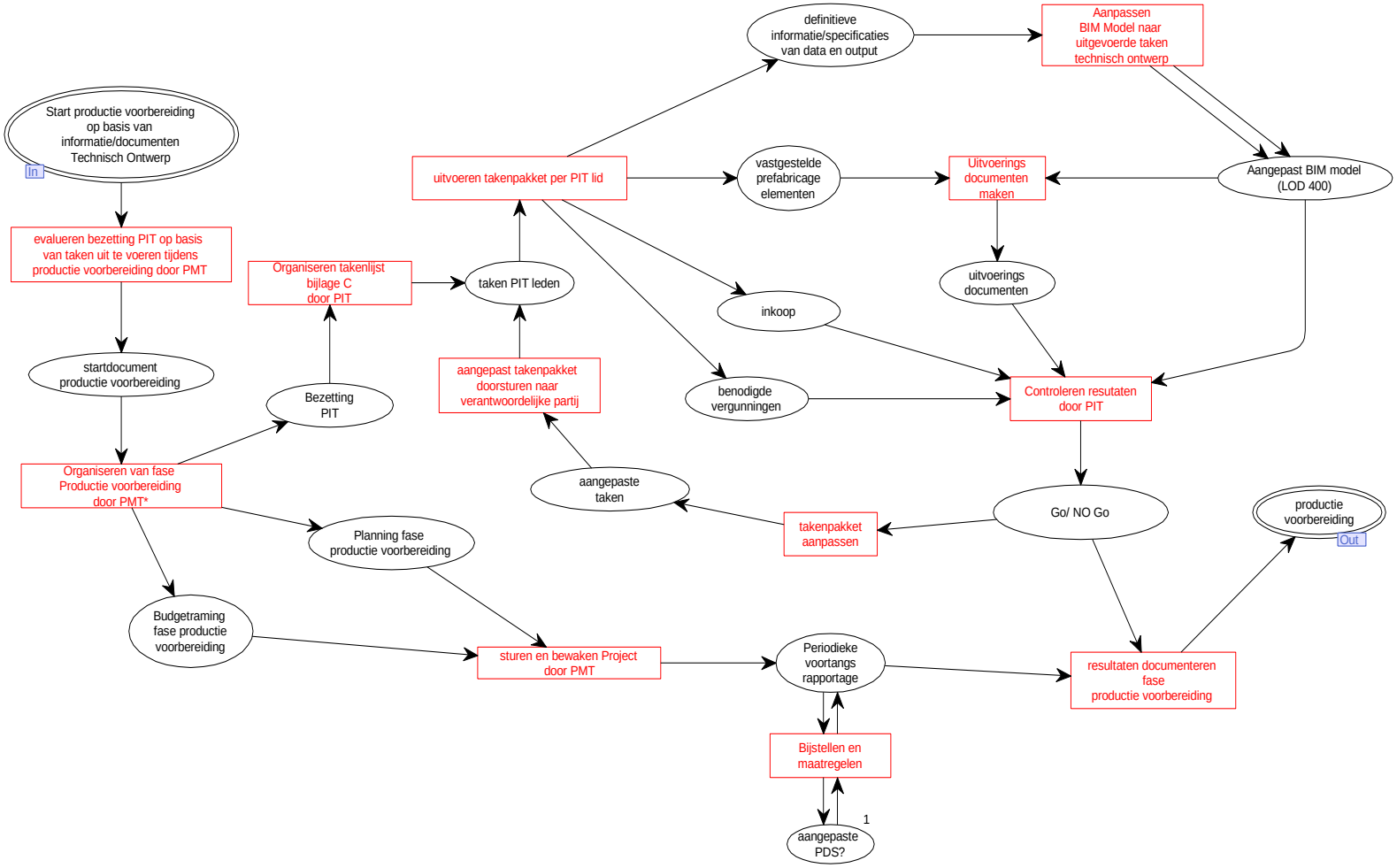


Figure 9, "productie voorbereiding" (agency review and buyout phase) modeled as a subnet

Appendix C, Petri net model with Breeam.nl

In this appendix the subnets of the original Petri net model, influenced by the addition of Breeam.nl to the design process, are displayed.

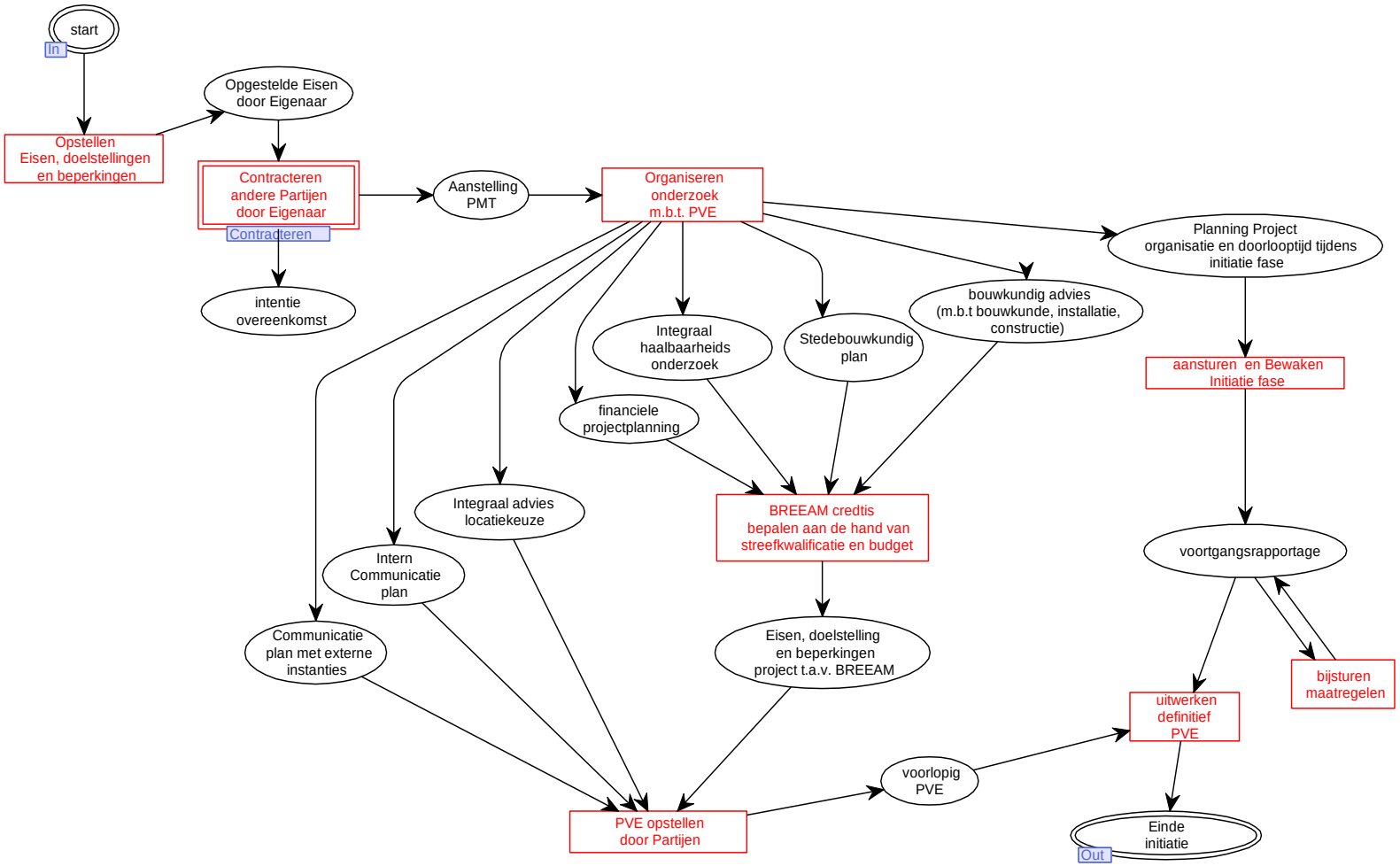


Fig 10, breeam impact on the ”initiatie” modeled as a subnet

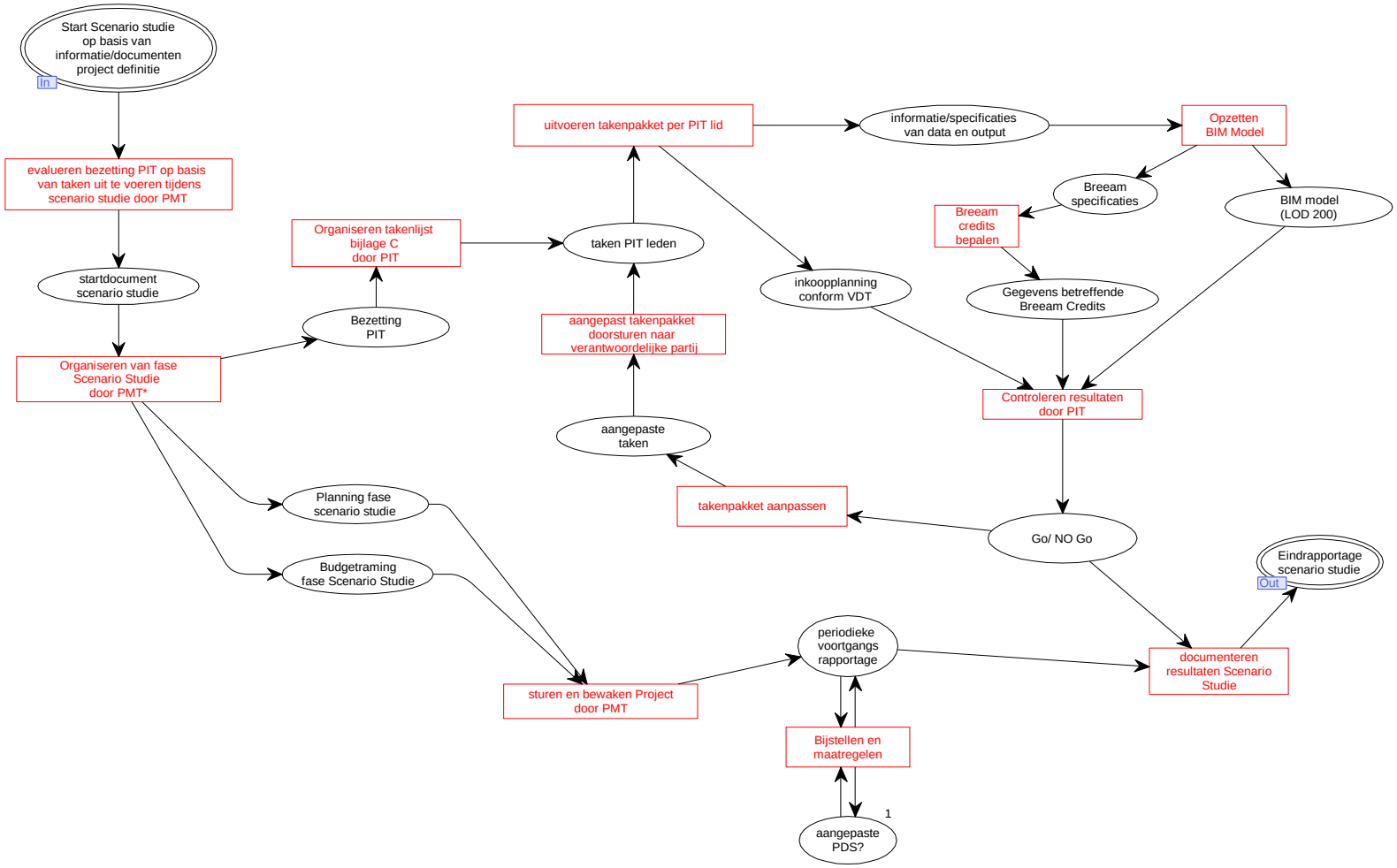


Fig 11, breeam impact on the "scenario studie" phase modeled as a subnet

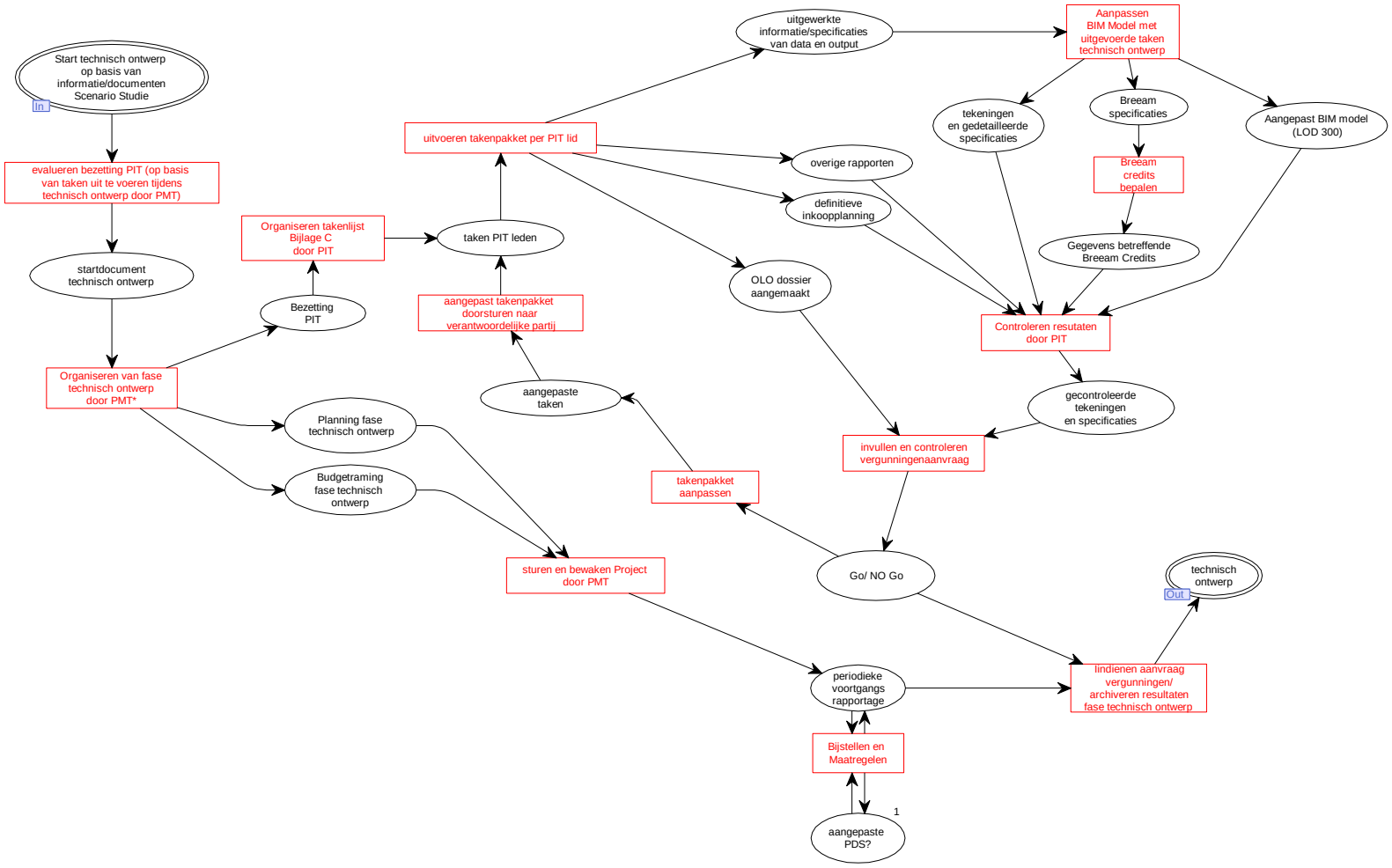
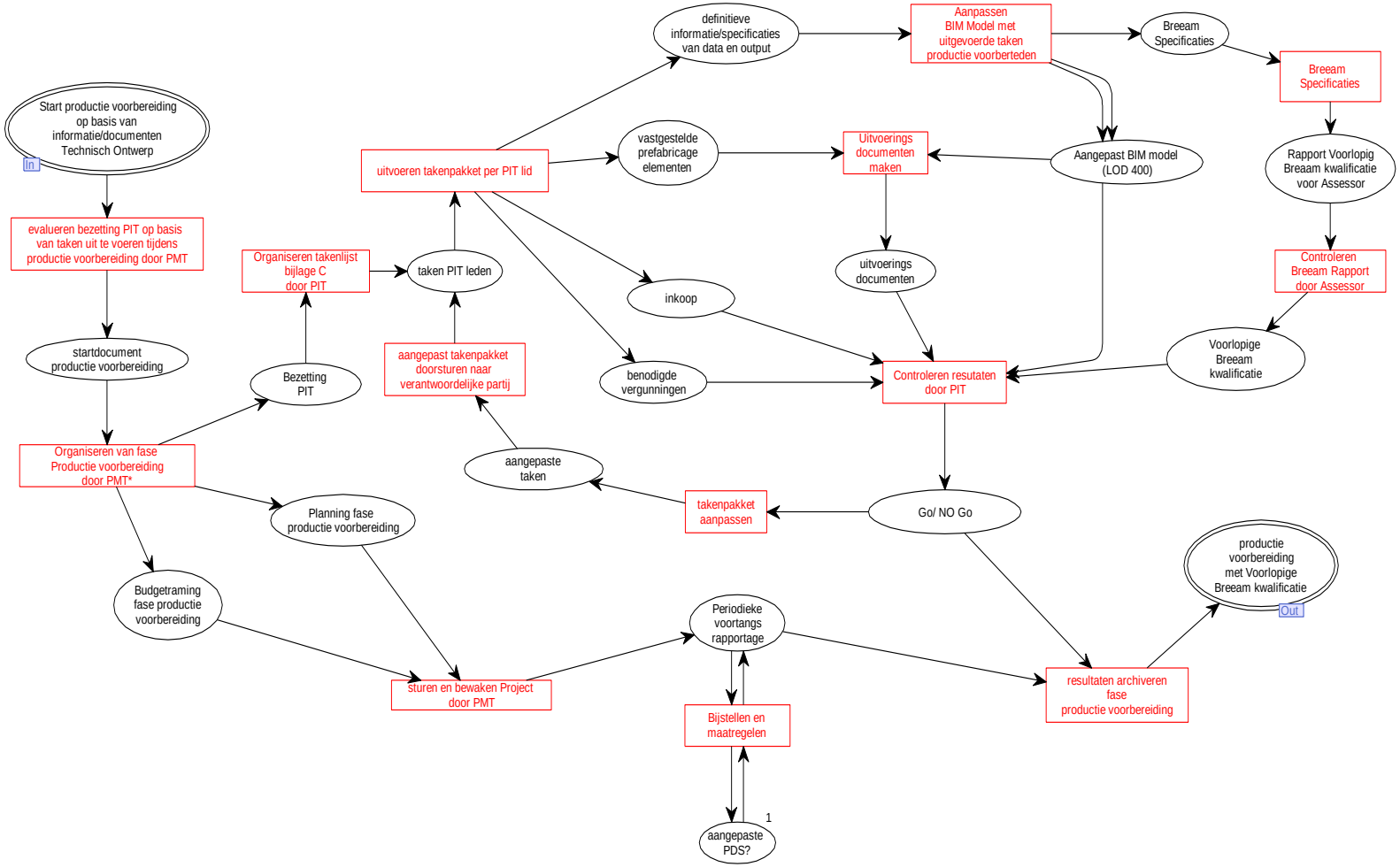


Fig 12, breeam impact on the "technisch ontwerp" phase modeled as a subnet



58

59 *Fig 13, breeam impact on the "productie voorbereiding" phase*