Data exchange analysis for property valuation on sustainability perspective

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Abstract. In real-estate domain, sustainable valuation and sustainable procurement are gradually accepted by different institutions all over the world. A large amount of research shows positive relationships between buildings' sustainable variables and observed property market values. However, the sustainability criteria in property valuation process is still lacking support data and standard information exchange methods. To enrich the fundamental database for sustainability assessment in property valuation and improve information exchange among different actors, this research proposes a holistic data interpretation of the information needed for the integration of property valuation and sustainability assessment. A standard information exchange method is further explored by referring to Building Information Modelling (BIM) related concepts (IFC/IDM/MVD). In this way, the comprehensive quantitative analysis of sustainability-related information in property valuation becomes tangible, and the accuracy and efficiency of property valuation will be improved.

1. Introduction

A plethora of research has shown that green buildings have a premium market price. Based on over 1200 green-rated buildings including office, retail, industrial buildings, hospitality and others, CoStar Group used standard regression analysis models and concluded the average LEED impact and Energy Star impact on sales price per square foot is a positive 9.94% and 5.76% respectively (Miller, Spivey and Florance, (2008)). Similar studies in Switzerland and UK found that property markets were increasingly paying premium price for the value-relevant sustainability features (Salvi, et al., (2008); RICS, (2013)). Therefore, research on the integration of sustainability assessment in property valuation process was required by real estate professionals and other market actors. Researchers and valuers tried to quantify the effects of sustainability-related features on property values directly (Kats, (2007)). However, the interpretation and application of sustainability measurement are still limited. This is because there is no available sustainability-related data on market values of properties or real estate professionals have limited knowledge and skills of sustainability assessment. To perform the sustainability assessment in property valuation more effectively, the current property valuation methods and procedures need to be improved and further developed.

Building information modelling (BIM), as a new technology for lifecycle project information exchange and management, has been developed by a great number of researchers and industrial professionals for sustainability assessment of buildings and infrastructure in the Architecture, Engineering, Construction and Facility Management domain (Eastman, (2008)). The application of BIM models in nature has the capability to create, collect, store and manage sustainability-related information for property valuation use. In addition, since no robust standard defines the specific requirements for data exchange of sustainability assessment in property valuation, current property valuation professionals have to acquire related information manually. This time-consuming process can be partly automated by using BIM related technologies: Industrial Foundation Class (IFC) standards, Information Delivery Manual (IDM) and the domain-specific Model View Definition (MVD).

In view of the potential benefits of BIM for sustainable property valuation, this research aims to provide a holistic data interpretation for sustainability assessment in property valuation and a standard information exchange framework for different actors. To achieve the above goal, this paper firstly reviewed 174 related documents and concluded sustainability-related parameters from them. After that, related information was defined in IFC format and extracted from BIM models using IDM standards. Finally, a case study based on advanced property valuation method was conducted and the trained machine learning model tested with lower prediction error. A valuation API was further proposed for the integration of machine learning models and BIM platform. This approach has the potential to reshape the hedonistic models already existed in property valuation.

2. The Current Status of Sustainability Assessment in Property Valuation

2.1 Systematic literature research on the integration of property valuation and sustainability assessment

In order to get a comprehensive understanding of current status of sustainability assessment in property valuation, this paper did a systematic literature which collected from 4 main academic databases namely Web of Science, Google Scholar, Science Direct & Scopus. The search criterion was devised as using two groups of keywords: (Property Valuation **or** House Price **or** Real Estate Appraisal) **and** (Sustainability Assessment **or** Green Certification) within (Title or Keywords). The initial search results – 715 documents (raw findings before removal of duplicates) breakdown into 6 search groups: Property valuation & Sustainability Assessment (217 documents); Property Valuation & Green Certification (76); House Price & Sustainability Assessment (72); House Price & Green Certification (133); Real Estate Appraisal & Sustainability Assessment (77); Real Estate Appraisal & Green Certification (140). In order to get rid of the duplicates, the 715 documents were imported into the same Mendeley Library folder with the number reduced to 234. After that, the 234 documents were manually checked by the authors and approved as relevant with sustainability assessment in property valuation, with the number reduced to 174 (Figure 1). These 174 files were further used for the holistic data interpretation regarding the database of property valuation and sustainability assessment in section 4.

According to the Appraisal Institute (2001), there are four fundamental forces influencing the property values: physical forces, economic forces, political and governmental forces and social forces. Recently, within the property valuation process, growing interest is shown on the social responsibility, financial benefit and potential risk reduction that sustainable development may bring into property valuation domain (Lorenz and Lützkendorf, (2008)). Figure 1 shows that the awareness of reflecting sustainability-related impacts in the traditional property valuation method is high and constantly growing among the general public in many countries. The complexity of sustainability and taking account this into different traditional property valuation methods require a significant change in the data collection and information exchange of property valuation professionals and other related market actors (Lorenz, Lützkendorf and Trück (2007)). Research and projects have been conducted to explore the possibility of characterizing the sustainability of a building by its environmentally related parameters (such as energy efficiency and lifecycle costing) according to the a specific internationally renowned green building labelling scheme such as LEED or BREEAM, but this is recognized as too short sighted due to the lack of holistic sustainability assessment consideration (Meins et al., (2010a)). Apart from energy efficiency and building ecology, social aspects and economic issues which also have parts to play in determining the sustainability assessment in property valuation.

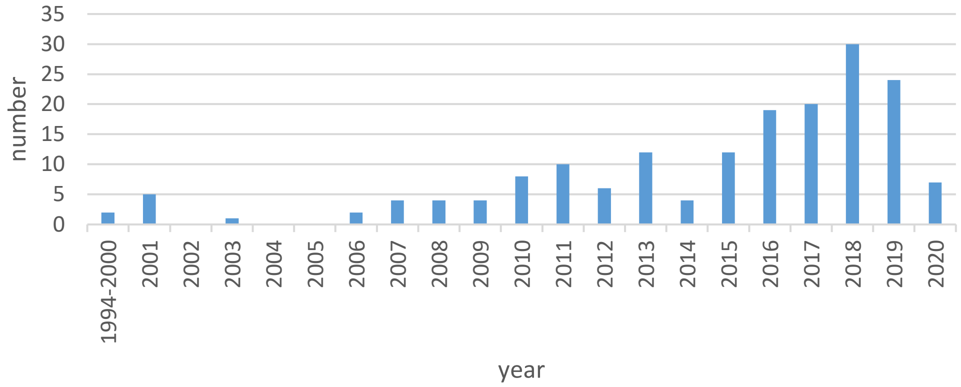

Figure 1: 174 research documents on sustainability assessment in property valuation from 1994-2020

2.2 Analysis of Quantitative Sustainability Assessment in Property Valuation

The environmental, social and economic benefits of sustainable buildings are generally accepted and extensively researched in the literature, which recognized as low lifecycle energy cost, energy efficiency, increased health comfort of tenants and being profitable and marketable than traditional buildings (Lorenz and Lützkendorf, (2008)). Researchers try to quantify the sustainable features by referring to direct or indirect financial gains or reduced property risks. For instance, Miller, Spivey and Florance (2008) compared the effects of sustainable features to LEED certificated buildings and Energy Star rated buildings in terms of rent and occupancy rate gains, increased sale price and lower cap rates. CASBEE system created a direct link between sustainability assessment and property valuation, taking into consideration of environmental quality and load reduction factors such as indoor heating and cooling, health and safety, indoor brightness and quietness, consideration of the landscape, water conservation and recycling, maintenance and operation schemes (Wong and Abe, (2014); IBEC, (2007)). Lorenz, Lützkendorf and Trück (2007) used property rating systems to economically assess the relationship between characteristics and attributes of sustainable buildings and reduced property specific risks, such as the flexibility and adaptability to reduce risks of market changes, environmentally friendly building components and materials to reduce the litigation risks. Lützkendorf and Lorenz (2007) tried to find the effects and benefits of different sustainable design features on different actors – developers and owners, tenants, society and environment.

3. System Design and Methodology

Building upon the research from the literature review, a novel system is proposed which enables the exploration of information management for property valuation on sustainability perspective. Figure 2 below illustrates the conceptual system framework, along with the adopted methodology for its development. In the next two sections, firstly, holistic data interpretation for the integration of property valuation and sustainability assessment will be achieved from quantitative analysis of related research publications and projects, industry standards and procedures. Secondly, related IFC datatypes will be defined based on the fundamental database and required information will be extracted from BIM models referring to IDM standards. Finally, a valuation API based on machine learning will be integrated into the BIM platform to achieve semi-automated property valuation on sustainable perspective.

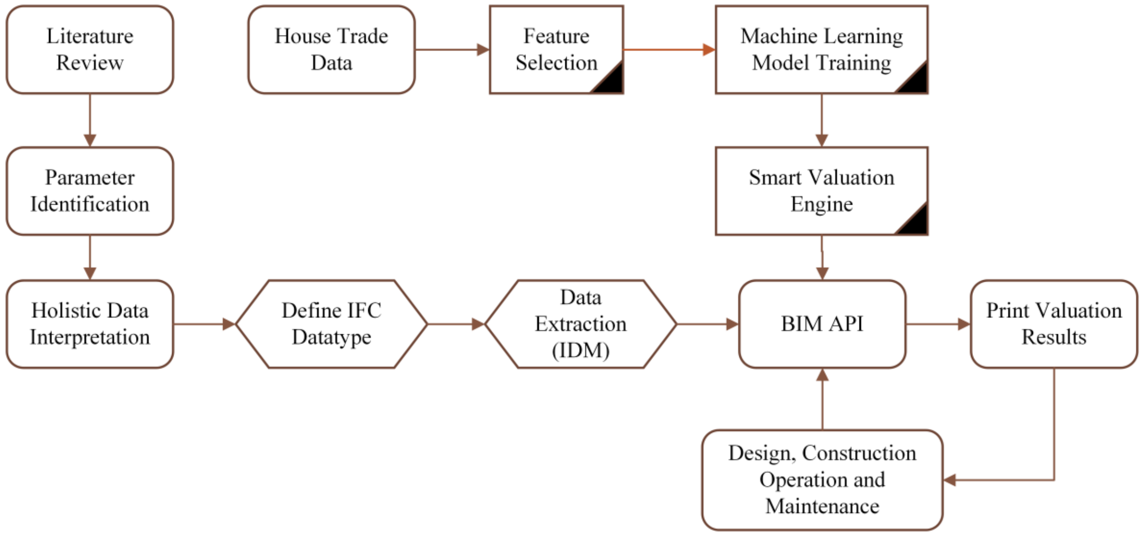

Figure 2: Conceptual system framework - data exchange analysis for sustainable property valuation

4. Data Exchange Analysis for the Integration of Sustainability Assessment in Property Valuation

4.1 Holistic Data Interpretation for Property Valuation on Sustainability Perspective

Collected from the 174 research documents including research paper, research projects and popular sustainability rating systems (LEED, BREEAM, DGNB and CASBEE) from different countries, the list of information contained in Table 1 (appendix) has been classified with 6 different types of information related to property valuation and sustainability assessment: information related to environmental quality, social and economic quality, functional quality, process quality, technical quality and site quality. Information included in traditional property survey and sustainability assessment are compared with information achievable within BIM related process. The yellow color stands for information needed for traditional property valuation and the green color stands for information needed for sustainability assessment, both of which may come from various sources. The light red in the 4th column means information required by both traditional property valuation and sustainability assessment. The dark red in the 3rd column means information can be defined and developed in the BIM related platform, which is the core for semi-automated property valuation.

4.2 Information exchange based on BIM related concepts – IFC/IDM/MVD

According to Ventolo (2015), the data collection in the traditional building survey can come from more than 40 data sources: regional government officials, property managers, professional journals, financial institutions, building architects, contactors, engineers and so on. All market actors in property markets can create their own sets of raw data in the building lifecycle, or they can collect and process information from other information source suppliers. Different market actors use different descriptive ways to interpret information in different data formats, which means information exchange issues will inevitably happen. These problems also exist in the integration of sustainability assessment and property valuation process.

To facilitate information exchange, this research uses standard information exchange technology referring to related BIM concepts. Firstly, related IFC concepts are defined for the integration of sustainability assessment in property valuation. The IFC data model, contains geometric information and semantic information, is an open and neutral object-based data format for standard description of architectural, building and construction industry (Liebich, (2013)). Table 2 in the appendix lists an example that shows IFC 4 entities and data attributes covering related information from the enriched database. The classifications of components and units are based on the rules of measurement for capital building works from RICS (2012). The definition of IFC entity and IFC attribute datatype refers to the IFC4 standard from buildingSMART International (Liebich, T. (2013)).

Secondly, required information is delivered using process map, which is created to cover the knowledge mapping of BIM models and property valuation on sustainability perspective. Figure 3 shows the process map for information exchange between architects, HVAC engineers and property valuers on sustainability perspective. The holistic data interpretation collected from literature and defined IFC standards provide guidelines for Architects, HVAC engineers and property valuers to create information when they are preparing the valuation models. The sustainability-related information is semi-automatically extracted from the enriched data models for sustainable property valuation.

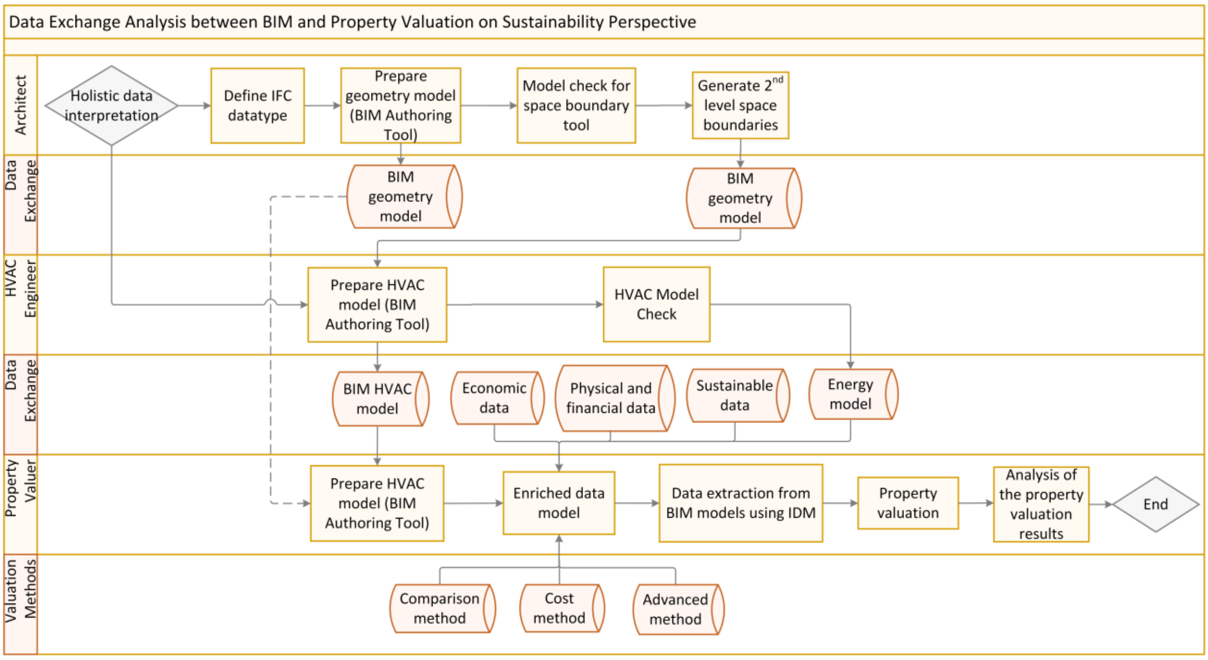

Figure 3: Process map for the information exchange between BIM and property valuation on sustainability perspective

5. Implementation and Demonstration – Case Study Based on Advanced Valuation Method

As Pagourtzi et al. (2003) concluded, there are traditional valuation methods (sales comparison method, DCF method) and advance valuation methods (data analysis methods). To fully perform the automatically information exchange, this research explores the use of the advanced valuation method using ensemble machine learning algorithms. The machine learning engine is trained with 700 traded houses from 47 different cities in America. The dataset contains 17 predicting variables, selected from 63 attributed by using gradient descent optimization algorithm. The dataset is divided into two groups: 70% for training dataset, 30% for testing dataset. After that, in order to find the best learning speed and the suitable complexity of the decision trees, the model hyperparameters are tested on Pycharm platform–which is an integrated development environment (IDE) specifically for the Python language. The model hyperparameters are finally set for training the ensemble machine learning engine: 1000 decision trees, learning speed at 0.1, maximum depth at 6, minimum sample leaf at 9. The code for the training model is showed below.

Code for the training model:

```
# Create the X and y arrays
X = features_df.as_matrix()
y = df['sale_price'].as_matrix()
# Split the data set in a training set (70%) and a test set (30%)
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.3,
random_state=0)
# Fit regression model
model = ensemble.GradientBoostingRegressor(
    n_estimators=1000, learning_rate=0.1, max_depth=6, min_samples_leaf=9,
    max_features=0.1, loss='huber', random_state=0)
model.fit(X_train, y_train)
```

Code for the prediction model:

```
from sklearn.externals import joblib
# Load the model we trained previously
model = joblib.load('trained_house_classifier_model.pkl')
house_to_value = [
    2006,# year_built          1,    # stories          4,# num_bedrooms
    3,   # full_bathrooms      2200, # livable_sqft     0,# garage_sqft
    0,   # half_bathrooms      2350, # total_sqft       0,# carport_sqft
    True,# has_fireplace       False,# has_pool
    True,# has_central_heating True, # has_central_cooling
    # Garage type: Choose only one
    0,   # attached            0,    # detached         1,# none
    # City: Choose only one
    1,      # Brownport ]
homes_to_value = [house_to_value]
predicted_value = predicted_home_values[0]
print("This house has an estimated value of ${:,.2f}".format(predicted_value))
```

After the machine learning model training, a Revit API is proposed to connect the smart valuation model to the BIM platform. The API helps extract IFC data from BIM models semi-automatically. The related data extracted from BIM is further tested by the trained machine learning model, with the prediction value of $587091.02, testing mean absolute error (MAE) at $59225.13, testing mean absolute percentage error (MAPE) at 10.08%. The MAE is the average of the absolute values of the prediction errors according to their magnitude. The MAPE, a measure of accuracy in a series value and usually expresses accuracy as a percentage, is calculated as formula 1:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right| \quad (1)$$

where A_t is the actual value and F_t is the forecast value. McCluskey et al., (2013) conducted a research on prediction accuracy of different modern approaches for mass appraisal, in terms of mean absolute percentage error, showing 10.40% for geographically weighted regression (GWR), 11.97% for ANN, 13.69% for spatial simultaneous autoregressive (SAR), and 12.27 for model regression modelling (MRM). Compared with these statistic models whose mean absolute percentage error are greater than 10.40%, this research shows the superiority of 10.08%.

Code for the testing:

```
# Find the error rate on the training set
mse = mean_absolute_error(y_train, model.predict(X_train))
print("Training Set Mean Absolute Error: %.4f" % mse)
# Find the error rate on the test set
```

```
mse = mean_absolute_error(y_test, model.predict(X_test))
print("Test Set Mean Absolute Error: %.4f" %)
```

6. Conclusions and future work

In this paper, firstly, a comprehensive database is collected from related literature for the integration of sustainability assessment in property valuation. Taking into consideration of the unique sustainability assessment method used in different regions or countries, this enriched database can be further developed for different sustainability rating systems as well as complying with the specific demand of the customers. Secondly, an efficient data exchange framework by using BIM related technology (IFC/IDM) is proposed for the efficient and cost-saving data collection and information sharing among different market actors. Lastly, a case study using advanced valuation method is further explored to connect the property valuation to BIM platform, and tested with the improved prediction accuracy. With this new information management framework, most of the information needed for property valuation on sustainability perspective can be semi-automatically extracted from BIM models. Consequently, fundamental improvements and changes can be made to property appraisal methods. In addition, the holistic data interpretation using bibliography analysis and information exchange framework under BIM platform presented in this paper has the potential for the information management of any further domain applications related to building and construction industry.

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Appendix

Table 1: Database for property valuation including sustainability-related information

Type of Information	**Subtype**	**Performance indicator and attribute**	**A**	**B**	**C**	**D**
Environmental Quality	Local Environmental Impact	Climate Change				
	Pollution	Noise from transport service and building service equipment, water pollution, land contamination, electromagnetic pollution				
	Land Use	Soil Characteristics				
		Layout, size, inclination, topography				
	Sustainable Resource	Rainwater use				
		Green area				
		Sunlight/Shading				
	Waste Water Volume	Waste water disposal				
Social and Economic Quality	Commercial Viability	Policy and economic situation				
		Demographic structure and development				
		Purchasing power, letting prospects, expected rates of return				
		Rental growth potential, inflation expectations, rental payments, other payments				
		Payments for construction, acquisition, disposal, payments for operating costs, marketing / letting fee, payments for revitalization				
		Number of tenants, Duration and structure of rental contracts				
		Vacancy rate, tenant fluctuation				
	Safety and Security	Location regrading natural hazards (risk of floods, landslides, collapse)				
	Lifecycle Cost	Water demand and price, energy demand and price				
	Indoor Air Quality	Sufficient natural air flow				
	Acoustic Comfort	Sufficient natural light				

Functional Quality	Visual Comfort	Good scene view
	Flexibility and Adaptability	Flexibility of use (residential, office, medical practice), adaptability to users
		Wheelchair accessibility
		Wheelchair accessible washrooms
		Usability of outside space
		Elevators (for all stories or not)
		Wide doors and wide halls
		Floor plan, storey height
	Brand Value	Green certification
		Famous designer
	User Control	Individual temperature controls
	Design/Aesthetic Quality	Architectural quality, Holistic monument
Process Quality	Sustainability Aspects in Tender Phase	Ecological construction materials, risks and impacts for the local environment and residence
	Documentation for Sustainable Management	Documented maintenance and servicing activities
	Urban Planning and Design Procedure	Public accessibility, quality of layout,
	Construction Process/Site	Quality control during construction (air-tightness, thermography, sound insulation)
	FM-compliant Planning	
Technical Quality	Basic Information	Structure, age, size, construction type, main construction materials
		Availability of green roofs/green facades
		Degree of revitalization
		Building equipment and appliances
	Sound Insulation	Noise Protection Techniques and Components
	Quality of the Building Envelope	Heat insulation
		Moisture proofing of the thermal building envelope
	Ease of Cleaning Building Components	Ease of conducing cleaning, building services and maintenance works
	Recyclability and Energy efficiency	Ease of recovery and recycling, efficiency of heating ventilation, air conditioning, rainwater use
	Immission Control	External and internal accessibility

	Infrastructure	Fitness				
	Quality of Indoor and Outdoor Spaces	Balcony, storage space				
	Safety and Security	Clear arrange routes for escape				
		Protection against burglary				
		Fire Protection				
		Quality of sanitary and electronic fixtures				
		Structural Safety				
		Durability of building components				
Site Quality	Local Environment and Policy	Visual context, building permission and planning regulations				
	Transport Access	Public transport, bicycle parking				
	Amenities	Area and distance to facilities (shopping, social and medical)				

A. Information included in traditional valuers' investigation
B. Information contained in sustainability assessment process
C. Information achievable within BIM related platform (design, planning, operation and maintenance process)
D. Information included in both property valuation and sustainability assessment

Table 2: IFC datatype response to sustainability assessment for property valuation

Type of data	Performance indicator and attribute	Component	Unit	IFC entity	IFC attribute datatype
Social and Economic Quality	Payments for construction, acquisition, payments for operating costs	General equipment	Weeks/ nr	IfcConstructionEquipmentResource	IfcQuantityTime
		Site Formworks	Weeks/ nr	IfcConstructionProduct Resource	IfcQuantityCount
Process Quality	Urban Planning and Design Procedure	Planning costs	m^2/km^2	IfcSite	IfcQuantityArea
		Design costs	m^2	IfcBuildingStorey; IfcSlab	IfcQuantityArea
Technical Quality	Structure, age, size, construction type, main construction materials, building equipment and appliances	Superstructure	m^2/nr	IfcSlab; IfcColumn; IfcBeam; IfcRoof; IfcStair; IfcRamp; IfcWall; IfcDoor; IfcWindow	IfcQuantityArea; IfcQuantityLength; IfcQuantityCount
		Fittings/furnishings	Nr	IfcFurnishing	IfcQuantityCount
Site Quality	Area and distance to facilities (shopping, social and medical)	Services	m^2/nr	IfcBuilding; IfcSpace; IfcBuildingStorey; IfcTransportElement	IfcQuantityArea