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Reconceptualizing object construction: the dynamics of Building Information Modelling in construction design

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Abstract

The article discusses the concepts of object and object construction through studying the collaborative use of Building Information Modelling (BIM) in construction design. It suggests that a combined BIM model in design can be regarded as an ideal or special object, as suggested by Ilyenkov in his theory of the ideal. The concepts of intermediary object and artefact help in analysing the cycles of construction of such an object in design. BIM models as modifiable digital artefacts contribute to their capability of functioning as tools of individual design work and collaboration as well as means of objectifying the outcomes of design cycles into intermediary objects. We argue that the uses of combined BIM models give birth to a new modality of spatial thought, perception and collaborative problem solving in construction design.

Introduction

Our research group has been involved in studying the implementation of Building Information Modelling (BIM) in the construction industry. We are interested in the nature of BIM as a digital artefact, the way its implementation is organized and the influence of its implementation on collaboration in multidisciplinary

design work and the relationships between designers, builders and maintainers in the construction process (Miettinen & Paavola, 2014).

As a term, BIM was introduced in the early 2000s. BIM, however, has had a long development history in computer-aided design—computer-aided manufacturing technologies and product models. Technically, BIM is composed of three-dimensional models combined with object-related quantitative and qualitative data of the parts of the building (Eastman *et al.*, 2011). It, therefore, allows advanced forms of visualization, modelling of the behaviour of the building (for example, its energy consumption or lighting) and the operative management of building projects. A decisive turn towards BIM came with the development of standards that enabled the transfer of information between ‘native’ or disciplinary design software models, that is architectural, structural and HVAC (heating, ventilation and air conditioning) models. The most important of these standards, Industry Foundation Classes, was published in 1997, and the first software was aligned with it in 1999 (Laakso & Kiviniemi, 2012).

Building Information Modelling implementation has also been introduced as a new way of working collaboratively in the construction industry. Models drawn up by different design disciplines (native models) can be united into combined models, which can in principle be used by all stakeholders of a construction project. This has been the foundation of a BIM utopia: all the relevant information about a building project could be presented in one model or data repository to be used by all stakeholders during the whole lifecycle of the building (Miettinen & Paavola, 2014). According to the proponents of BIM, this possibility would revolutionize collaboration both between designers and between designers and other stakeholders in the construction industry and would lead to an integrated way of working. An integrated project delivery would transcend the fragmentation of construction projects, which may typically involve tens or hundreds of agents with a wide range of interests and capabilities (American Institute of Architects, 2007; Succar, 2009). BIM implementation is expected to eliminate errors, improve the quality of design and ultimately radically increase the productivity of the construction industry, which has for decades lagged behind the development of productivity in other industries (Crotty, 2012). Due to this shortcoming, the construction industry needs to develop more collaborative ways of working with relational contracts (Miettinen & Paavola, 2014).

We will discuss the characteristics of BIM-mediated collaboration and the consequences of its implementation through the results of a study of a school renovation project in eastern Finland in 2011–2012 (see also Kerosuo *et al.*, 2015). Nine different BIM-related software programs were used by the designers in the project. The software tools were first used separately by the three main design disciplines: the architects used ArchiCAD, the structural engineers used Tekla Structures and the HVAC engineers used MaciCAD and Dialux. With these tools, they produced ‘native models’: architectural, structural or HVAC models. After that, special software tools (e.g. Tekla BIMsight) were used to combine the native models into combined models. The combined models were used to check the compatibility of the native models or to detect clashes between them (e.g. with Solibri Model Checker). Thirdly, HVAC engineers used special software (Riuska) for energy simulations. A basic benefit of modelling in construction design is seen in their use in cycles where the designers work separately with their native models and then from time to time join together to study the results compiled into a combined model. The evolving combined models, therefore, constitute a central tool of collaboration. Their final version can be called the ‘as-designed model’, providing the basic plans for the construction of the building. In this article, we study the construction of these combined models as an ideal or special object and intermediary artefact in the design process. Such an object is imagined and future-oriented, yet simultaneously artefact-mediated and realized through consecutive intermediary objectifications.

We will proceed in the paper as follows. *Firstly*, we briefly review the use of the concept of object in

activity theoretical studies of work and design. We aim at specifying the senses in which BIM models may be regarded as an object of design work. *Secondly*, we introduce the concept of the 'ideal object' based on Ewald Ilyenkov's theory of the ideal. This concept refers to a special material object (e.g. a model) that is modified in the process of design without changing the real object (a building). *Thirdly*, we review the object concepts used in the design literature and suggest that the concept of an intermediary object or intermediary artefact helps in understanding how a special object is collaboratively constructed. This object thus provides means of making sense of the cycles of collaborative design that gradually form an 'as-designed' model, which functions as a concrete representation and plan for the construction of the forthcoming building. BIM models – like digital artefacts in general – are highly modifiable and updatable, which contribute to their capacity of functioning in the design process as tools of individual design work, tools of collaboration, objects of joint attention and intermediary objects to which the outcomes of the cycles of design are objectified. The term artefact refers to all of these functions. *Fourthly*, we will analyse the changes in collaborative problem solving resulting from the implementation of BIM in joint design meetings. We will argue that contrary to many views of digital objects as 'immaterial' or 'intangible', BIM models provide new forms of spatial concreteness shown, for example, in the high proportion of indexicality in the meetings. We examine how activity theory, especially the interpretation provided by Lektorsky, helps in understanding the perception and problem solving related to the use of BIM models in designers' collaboration.

The uses of the concepts of object and object of activity in the study of work and design

A.N. Leontjev famously introduced the concepts of an object of activity and object-orientedness in cultural–historical activity theory. Russian and German languages have separate words for an object (objekt in both languages) as a material thing out there and for an object of activity (predmet, *Gegenstand*), an object of conscious transformation by humans able to resist their projections (Kaptelinin, 2005). In the English language, the term object is used for both meanings, which may be a cause for confusion. Leontjev (1978, 52) gave two basic meanings for the concept of 'object of activity'. Firstly, it has a dual nature as something given and as something imagined and projected.¹ This definition aims at surpassing the Cartesian dualism between the objective (given) and the subjective (imagined) and underlines that human thought needs to be studied as a part of practical activity, that is as bodily transformative interaction with the environment, and can therefore be characterized as objective activity. Secondly, Leontjev stated that the 'object is a real motive of activity' and that an activity is recognized based on its object (Leontjev, 1977, 52): 'The main thing that distinguishes one activity from another lies in the difference between their objects. It is the object of activity that endows it with a certain orientation. In the terminology I have been using, the object of activity is its *motive*.' This statement was related to Leontjev's distinction between the goal-oriented actions of individuals and groups and collective activity based on a division of labour. Following the Marxist tradition, Leontjev thinks that work is a paradigmatic type of activity. When Engeström (1987) further developed Leontjev's ideas into a theory of expansive learning, he located these concepts in the context of the political economy, that is in the context of the production and consumption of commodities in a capitalist society (e.g. Engeström & Blackler, 2005). In this way, the concepts, which were developed into a psychological theory, became a means of analysing the transformation of work activities in society and have been applied in the study of various types of work such as health care, teaching, scientific research and the design of information and communication technology systems (Engeström, 1990; Miettinen, 1998; Kaptelinin & Nardi, 2006).

In the context of work development, the term object of activity has assumed a double meaning. On the

one hand, it refers to the purpose or aim, which is the motivating background rationale of an activity and a horizon for actions that need to be reinterpreted in a changing society (Engeström, 1990). The joint reflection on the changing historical circumstances of an activity, the definition of its contradictions and the formulation of 'a new model of activity' (or a zone of proximal development) in interventionist studies serve such a historical reinterpretation. The second meaning of the object of activity is the concrete object of activity, something that is designed and produced and which assumes the form of a product, a service or a commodity. The relation of these two is sometimes characterized as an 'instantiation' of the motive of the activity (Nardi, 2005) or a separate type of a 'project object' (Hyysalo, 2005). The expression 'construction of an object' (product, service, information technology system and building) was partly established because of the influence of constructivist science and technology studies that theorized and analysed the production of facts and technological artefacts.² In analysing the construction design in this paper, we focus on the latter meaning of the object of activity.

In the 1990s and 2000s, new dimensions and meanings of 'object' were taken up. These encompass its complex and contradictory, open-ended, multifaceted and expanding nature. This complex and contradictory nature (referring to the functional complexity of objects to be constructed) was discussed in product development literature and in science and technology studies (Hobday, 1998; Miettinen, 1999). Complex products are composed of subsystems, the design and construction of which call for the contribution of a different kind of expertise. Correspondingly, different actors have different interpretations of the object. The contradictory nature of objects refers to the tension between the use and exchange value in them, as well as to the differing interests of the participants that need to be negotiated as a part of object construction (Miettinen, 2005).

Karin Knorr-Cetina has introduced the concept of 'epistemic object', analogous to an object of inquiry in science in which 'the lack in completeness of being is crucial' (Knorr-Cetina, 2001, 182). Knorr-Cetina (2001) argues that in a contemporary knowledge society, the objects of professional work are rapidly changing. Compared with mass products or services, these objects are ever more complex and dispersed and are in constant need of being redefined. This is why they can be characterized in terms of open, constantly unfolding epistemic objects. In focusing unilaterally on the epistemological dimension of an object of activity, this argument may risk leaving the social-practical nature of activities in the margin. The theme of the open and expansive nature of objects has been further developed by introducing the term 'runaway object', ambiguous large-scale global phenomena which are under no one's control and which have far-reaching consequences that are difficult to anticipate (Engeström, 2008). Totally new forms of transnational distributed agency are needed in order to tackle such objects and problems.

The increased complexity of objects is visible in both the construction and information and communication technology industries. The sheer size of buildings and the complicated devices and technology embedded in them have increased the number of contributors and, correspondingly, the need for coordination and collaboration.³ Constant negotiation between the stakeholders is needed to stimulate collaborative design and construction. In information system research, this expansion is expressed in the redefinition of the unit of analysis. Several authors suggest that instead of digital artefacts or information systems, digital 'infrastructures' need to be designed (Tilson *et al.*, 2010; Monteiro *et al.*, 2013). The increased number of relevant stakeholders has created the need to understand how they are able to collaborate and coordinate their actions. The concept of boundary object, originally introduced by Star & Griesemer (1989), has been used to make sense of this problem (Gal *et al.*, 2008; Whyte & Lobo, 2010). The terms object or object of activity have been interpreted in several ways, and new meanings or layers have been introduced in the last two decades.

The ideal object of design

Two key theoretical concepts of CHAT are mediation and object-orientedness. Correspondingly, the concepts of internalization and externalization constitute the mechanisms through which the interaction and co-evolution of an individual and culture is realized. Vygotsky (1986) studied the process in which external forms of activity and communication – he focused on language use – are internalized. In contrast, the philosophers of activity theory, Evald Ilyenkov (1977) and Vladimir Lektorsky (1980), underlined the significance of the reverse process, objectification, in which psychological images of thought become objectified through activity into cultural artefacts. Writing a paper is a part of a thought process, and the objectified outcome makes it communicable to others and potentially – when the outcome is published and printed – realized as a part of material culture. In the same vein, drawings, software programs and artworks, machines and buildings become part of culture, constituting a foundation for further cultural development and learning.

The objectification of thought in communication and text are not sufficient for making sense of human activity. They must be seen in a close unity with the transformation of objects (Lektorsky, 1980, 153):



Communication of knowledge presupposes objectification of knowledge not only in the form of texts or utterances but also of man-made objects carrying socio-cultural meaning. Epistemology therefore must analyse object-oriented activity in the unity of its practical-transformative, cognitive and communicative functions, as the basis of the entire cognitive process.

This requirement is also characteristic of other approaches of practical materialism. In the *Quest for Certainty* (1988/1929, 232), Dewey calls for a Copernican revolution in epistemology in which a 'shift from knowing which makes a difference to the knower but none in the world to knowing which is a directed change within the world' is needed. From the point of view of the internalization of means and of modes of activity developed by previous generations, objects and artefacts play a foundational role as carriers of the socio-historical experience of humanity or a disciplinary community. Lektorsky (1980, 137) characterizes this role as follows: 'the instrumental man-made objects function as objective forms of expression of cognitive norms, standards and object-hypotheses existing outside the given individual.'

In developing the concepts of human activity and thought in his theory of ideality, Ilyenkov uses, following Marx, a comparison of the constructive activity of animals and humans to clarify his position (1977, 276):



Man is distinguished from beasts by the existence of an ideal plane of activity. But what (..) distinguishes the most incompetent architect from the best of bees is that the architect has built a cell in his head before he constructs it in wax. A labour process ends in the creation of something which, when the process began, already existed in the worker's imagination, already existed in an ideal form. (Karl Marx, Capital Vol I, p. 170)

An insect's forms of activity are innate, inherited together with the structural and anatomical organization of its body. In human activity, no form of activity or faculty is inherited together with the organization of the body. All forms of activity (active faculties) are passed on only in the form of objects created by man for man. Ilyenkov continues by explaining that for an activity in the ideal plane, a special object or artefact is needed. With this special object, the agent can operate, up to a certain point, without touching or changing the real object. When explaining this, Ilyenkov returns to the example of an architect. The

architect builds a house not simply in his head but on the plane of a drawing board by using a multitude of tools and artefacts.



He thus alters his internal state, externalizing it and operating with it as with an *object distinct from himself*. In changing it he potentially alters the real house, i.e. changes it ideally, potentially, which means that he alters *one sensuously perceived object instead of another*. In other words activity on the plane of representation, altering the ideal image of an object, is also sensuously perceived image of the thing to which it is directed. (1977, 280)

Ilyenkov uses the terms 'special object' and 'ideal image of an object' in referring to what is altered in design work. We use the term 'ideal object' and think that it helps to clarify the role of the drawings and models used in the design process. The image of a final, material object is actively moulded by working on a special object (without changing the final object). A model and its drawings constitute an ideal object that exists in a different material form (as drawings or 3D models) and does not coincide with the final object of production and construction. This is clearly the case in the construction of buildings. The final drawings or the model are not complete enough for construction. The designers are not able to take into account all the conditions of the construction of a building, and the builders must form their solutions in order to complete its construction.

The design process can be analysed in terms of a gradual construction of an 'ideal' or special object. This is well depicted by Schmidt & Wagner (2004) in their study of the systems of computer-aided design plans and drawings in architectural design. According to them, these plans and drawings are objectifications of a thing-to-come. They incorporate the project's trajectory, absorbing the decisions and changes that are made as the plans are gradually detailed and modified. These are the (Schmidt & Wagner, 2004, 363–364)



means of making the not-yet-existing and in-the-process-of-becoming field of work immediately visible, at hand, tangible (...). They serve as objectifications of the construction-in-the-making and are, as such, the immediate object of their work; they are what is looked upon, inspected, gestured at, discussed, modified, annotated etc.

Drawings as a tool of thinking and collaboration have been discussed in the literature on architectural design. Lawson explains that (2000, 241) a 'drawing can ... take over and become a focus of attention replacing the object being designed in the affections of the designer'. Drawings can be seen as attempts to freeze and hold constant some limited aspects of design and represent a kind of a 'what if' tool (241). Lawson points out that in architecture, drawings 'not only represent the built object, but the process of drawing can also represent the process of making the object'. This process of making is a process in which 'designing, detailing, discovering, building, testing and discussion take place as simultaneous activities' (ibid., 248). We think that many of these simultaneous activities can be performed collaboratively more easily with BIM models than with the use of drawings alone, which still continues to play a role in the construction design (Harty & Whyte, 2010).

We can summarize the concept of the ideal object as applied to the study of design and modelling in four determinants. (1) An ideal object is a representational object or artefact developed in design without changing the real object. (2) It is ideal because it is an outcome of the imagination, thinking and collaboration of the designers, only realized by the use of culturally given artefacts and forms of activity and through objectification into intermediate outcomes. Ilyenkov explains this interconnectedness (1977,

263): 'the object proves to be idealized only when the faculty of actively recreating it has been created, relaying on the language of words or drawings, when the faculty of converting words into deeds, and through deeds into things, has been created'. (3) An ideal object refers to and represents a material object, but as a potentiality, something needed, something to be constructed and created. (4) An ideal object is modifiable and allows experimentation with different solutions and their simulation, which is not possible when moulding or constructing a real material object or product. In the construction of a product, the solutions implemented are irreversible or the corrections to what has already been done are expensive.

Design as a construction of intermediary objects and artefacts

Design work has been extensively analysed in terms of the collaborative use of different visual and external representations. Ewenstein & Whyte (2009) and others (Deken & Lauche, 2010; Whyte & Harty, 2012) have emphasized the multidimensional and evolving nature of objects in the collaborative design of buildings and product development. According to them, visual representations such as sketches embody design knowledge, but at the same time, they have almost an 'agential role' of showing what is 'lacking, wanting and unfolding' in the sketches themselves (Ewenstein & Whyte, 2009, 22). In order to find conceptual tools for understanding an evolving object in design, they discern 'boundary objects', 'epistemic objects' and 'technical objects' (ibid., 10). They also describe visual representations as having the characteristics of both boundary objects (usually interpreted as stable and concrete thing-like artefacts) and epistemic objects (which highlight the dynamic, unfolding nature of the process). Their distinction seems to be missing concrete thing-like artefacts, which are at the same time modifiable and editable, or concrete and dynamic. These artefacts would be closer to the notion of 'intermediary object' or 'intermediary artefact'.

Vinck has used the notion of intermediary object for physical and digital artefacts such as sketches, drawings, guidelines, models and documents that are used, produced and disseminated in engineering design practices and collaboration networks (Vinck & Jeantet, 1995; Eckert & Boujut, 2003; Vinck, 2011). This term has also been used to emphasize materiality and the more active role of external artefacts in the design process than is traditionally assumed (Vinck & Jeantet, 1995; Deken & Lauche, 2010). These meanings are, however, quite general characterizations of any artefact. We find three more specific meanings of the term to be more useful in the analysis of uses of BIM models. Firstly, intermediary object has been used to refer to the open and evolving nature of the design process instead of the traditional model of design as linear and sequential (Vinck & Jeantet, 1995; Ewenstein & Whyte, 2009). Secondly, it can refer to the intermediate *stages* and the evolving nature of the artefacts produced during the design process (Boujut & Blanco, 2003; Deken & Lauche, 2010). Third, because of the editable and modifiable nature of digital artefacts, they can be flexibly constructed, used and transformed collaboratively.

The term intermediary object can be used to analyse the construction of an ideal or special object, as suggested by Ilyenkov. This term well depicts the nature of the design process as composed of cycles of collaborative design during which the disciplinary native models (architectural, structural and HVAC) produced by different design disciplines using special-purpose software are fused into combined models. These models are simultaneously a partial outcome of joint work in the process towards a complete plan for construction as well as a means of joint reflection and problem solving concerning the following cycles of design. These cycles of collaborative design gradually produce a 'finalized' or an as-designed model, that is a model that constitutes the foundation of the construction of the forthcoming building.

We call combined BIM models both intermediary objects and intermediary artefacts because they function as tools of collaboration in design meetings. They are intermediary objects of design activity in the sense

of being objects of joint transformation and intermediary outcomes of the cycles of design. The term artefact – a man-made object – does not distinguish whether an artefact is an object or a tool in an activity. Lektorsky uses the expression ‘instrumental man-made object’ (1980, 27), which refers to an object functioning as a means. It seems to us that a novel feature of BIM models as intermediary artefacts is their capacity to play several functions in the course of a design process: a tool of disciplinary design work, a tool of collaborative problem solving and an evolving plan for the construction of a building. Other functions are emerging, without doubt, in BIM-mediated collaboration with clients and users, or with suppliers of construction materials.

Perception and object-related problem solving in the use of BIM models in a renovation project

Lektorsky speaks of ‘object-related practical activity’, underlining that all forms of cognition, starting with perception, are a part of practical activity involving material objects. These objects are not static and passive objects of reflection but a part of the active modification of the world by humans (Lektorsky, 1980, 134). How does this object-related practical activity fit with modern digital technologies? Properties of digital artefacts, such as their editability, distributedness or their unstable or unbounded nature, may seem to separate them from other artefacts (Ekbia, 2009; Kallinikos *et al.*, 2010; Yoo *et al.*, 2010). This is relevant to information scientists’ discussions on specific features of virtual or digital materiality (Yoo *et al.*, 2010; Blanchette, 2011). Blanchette (2011) has, however, criticized the ‘romantic immaterialism’ of those views, which maintain that ‘information can be free from material constraints’ (*ibid.*, 1043). We maintain that especially in order to understand the uses of digital technologies, various material and practical aspects need to be taken into account. The activity theoretical approach is at odds with the idea of the intangible and immaterial nature of digital artefacts or digital technology (Yoo, 2010; see also Kallinikos, 2009; Leonardi, 2015).

In the area of engineering design, ethnographic studies have analysed the role of artefacts and visual representations, thus far mainly in the form of the paper drawings in design work (Bucciarelli, 1994, 2002; Henderson, 1999). Sketches, drawings and plans are basic components of designers’ communication, which is seen in the intensive indexical or even tactile engagements of designers with these artefacts in design meetings (Henderson, 1999; Ewenstein & Whyte, 2009).

In the project we followed, BIM models were collaboratively developed and shared in two main ways. The first was clash detection conducted by a BIM expert representing the contractor. This required all of the design partners (the architects, HVAC engineers and structural engineers) to update their own design models at certain time intervals. These design models were then compiled by the BIM expert into a combined model with specific BIM software. The resulting model revealed obvious clashes in the design models of different design areas, such as pipelines clashing with structural elements. The clash detection lists were emailed to the designers, who were then supposed to update their models accordingly. The designers, however, did not find the clash detection lists very useful. Most of the hundreds of clashes recognized were according to them rather trivial clashes produced by the strict criteria of the software. The designers were doubtful on the usefulness of clash detection lists, which seemed not to reveal real design problems.

Building Information Modelling models were, however, used more collaboratively between the designers in the project. The project manager had decided that besides clash detection lists, face-to-face design meetings were needed with all the design partners at which they checked the current stage of the design plans and their compatibility. In these meetings, they looked at the fit between different design models and

discussed problematic places in their designs. For these meetings, a combined BIM model was updated. The technical procedure was quite similar to the clash detection method, but the combined model was used differently in these face-to-face meetings. The combined model was a basis for discussing the design problems in the plans.

The concrete, tangible features of the BIM models became clearly visible in the design meetings where the designers reconciled their design plans together. These were long one-day meetings during which the designers spent most of the time looking at a projection of the combined model on a screen on the wall (Figure 1). They discussed the design problems in various places in the building to be constructed by zooming in and out of the combined model and pointing at locations on it. A prominent feature of these meetings was the frequent use of indexical signs during the discussions. The participants indicated those places in the plans that were problematic using the cursor, with indexical utterances, with their hands and by zooming in and out and moving the model. The first design meeting lasted 7.5 h and the second 7 h. In the first meeting, the designers discussed 66 issues, that is a constellation of problems on a specific issue. In total, 51 (77%) of these were discussed by indicating the place in the combined model, and for only 15 issues (23%), the discussion contained periods where they were not looking at the screen. The principal designer (or sometimes the structural engineer) used the BIM software, and he moved the combined model and zoomed in and out of it to focus on those places in the 3D model which were discussed.



Figure 1.

[Open in figure viewer](#)

Designers discussing the combined model in one-day design meetings.

The model on the screen operated as a tangible means of presenting and discussing the design problems and solutions, which was supported with indexical talk. A short excerpt of the talk shows the frequency of indexical utterances (here, a HVAC engineer is asking about a specific place where the ducts and pipes should be placed to go through the structures, while at the same time, the principal designer was showing that place in the model on the screen):

“ Yes, it is *this one here* , if you can take it a bit *upward* . You cannot see all the items *yet* .
Here – if we go with ducts through, with pipes through, so the pillar is *here* , the middle third is *here* . Can we go through with ducts *here* ? Water and drain. *There* you can actually see the water and drain, to make it clear I have changed it *here* when *here* starts that middle third *this way* . How is it with *these kinds* , can we make a void *here* ? [Indexical utterances highlighted]

One typical problem discussed in these meetings was whether enough space was available for all the necessary pipelines in the structural elements so that the structures would still be sound and the end result would be aesthetic and functional. In this sense, these models are not just visual representations of the building but kinds of spatial simulations of the design solutions and how these design plans function together.

Lektorsky's theory of practice-related cognition and objects can be used to make sense of the nature of the use of BIM models. The mediating objects refer to the characteristics of objects existing independently from these mediating objects and also have features of their own (Lektorsky, 1980, 139). In observing and manipulating the model, the designers simultaneously imagine and solve the problems of the 'final' object system to be constructed, that is the building.

“ Visual representation always points to a real object (...). It is therefore impossible to separate in consciousness the content of a visual image from the content of the object presented in it (although the image itself is realized as different from the object). When consciousness attempts to make the content of a given visual image its object, it discovers that it deals with the content of the real object itself presented in this image. (Lektorsky, 1980, 147)

The designers do not start with the kind of 'sense data' emphasized by traditional empiricism but by perceiving the properties of physical objects (ibid., 123). They start with what Lektorsky calls an 'object hypothesis', which is embodied in the mediating artefacts. In studying and elaborating on the models, the designers perceive the affordances of material entities (Gibson, 1979; Norman, 1988). In the case of a building model, these are the physical properties and behaviour of the materials and structures that are meaningful in design. The knowledge of these affordances is based on both practical experience of being involved in the construction of houses and professional knowledge acquired in education. In evaluating the constructability of the solutions, they resort to their prior practical experience. Their knowledge, however, is always incomplete since the designers are not experts in construction. This is shown by the need to complement the design plans during the construction phase. On the other hand, when looking at the structures and elements in the model, construction engineers are able to 'see' their durability based on specific engineering knowledge, and the architects may perceive architectural clues and aesthetic properties in them (Lawson, 2000). In this sense, a subject 'can perceive those aspects of objects which do not act on his sense organs' (Lektorsky, 1980, 124).

In the philosophy of science, a central discovery in the critique of empiricist theories of science has been

the theory-ladenness, or practice-ladenness, of observation (e.g. Chalmers, 1990, Miettinen, 2000). This idea largely corresponds to the concept of mediation by signs and tools suggested by activity theory. Our culturally adopted concepts and knowledge influence our perception from the outset. John Dewey characterized the cultural mediatedness of observations as follows (Dewey, 1988/1925, 40): 'experience is already overlaid and saturated with the products of the reflection of past generations and by-gone ages. It is filled with interpretations, classifications, due to sophisticated thought, which have become incorporated into what seems to be fresh naïve empirical material'. A scientific observation, on the other hand, is a practical accomplishment. It is a result of work, accomplished with a whole arsenal of instruments (Chalmers, 1990). Any scientific observation already includes an interpretation of whether the organization of the observation and experimentation was satisfactory or not.

Similarly, a 3D model is a practical accomplishment based on the use of a complex set of instruments. Here again, Lektorsky's conceptualization can be used of what is embodied in instrumental objects: an object hypothesis, standards and cognitive norms. These both direct and limit the uses of models and problem solving. Some of the software tools are only partially interoperable. One limitation of BIM modelling is that the combined models cannot be moulded collaboratively. A new cycle of design following the study of the combined model is performed separately by each of the designers using native model software.

The implementation of the digital 3D models used in design has changed design collaboration: in contrast to drawings, these models can be put together and used to compare the suggestions and plans made by the different designers. Simultaneously, we argue that their use has given birth to a new modality of spatial thought, perception and problem solving as outlined earlier. This is in line with Wartofsky's historical theory of perception (1979), studies of collaborative cognition and perception (e.g. Goodwin, 2000, Tomasello *et al.*, 2005) and modern studies of the origins of language (Dor *et al.*, 2014). Both perception and communication are a part of collaborative object-oriented practical activity and are mediated by historically developed instruments and forms of action.

Conclusions

In this article, we have used Ilyenkov's theory of the ideal and Lektorsky's theory of cognition to provide an account of building design using BIM and the influence of its use on design work and collaboration. In his theory of the ideal, Ilyenkov characterized the emergence of an ideal plane of human activity as one in which human subjects mould a special object (e.g. a system of drawings or 3D models) instead of transforming the final material object directly into a use value. This is also necessary because the moulding of a material object is an irreversible process in which changes to what has been done are impossible or costly. The design process can be studied as a process of constructing such a special object using a number of mediating artefacts. As Lektorsky suggests, these artefacts are embodied forms of prior human activity and knowledge providing an object hypothesis, cognitive norms and standards for the design work.

We find it useful to characterize the gradual construction of an ideal object by using BIM models as the intermediary objects or artefacts suggested in the design literature. They are partial, incomplete and reworkable external representations or data, or the rich plans of a building. They are not static like a boundary object nor endlessly open and modifiable like epistemic objects, but become closed in the final special object, an 'as-designed model' that is a plan for the construction of the building. These changes can be included in the model, in which case the model is called an 'as-built model'. In practice, however, this is not done, mainly because of the division of labour between designers and those responsible for the

construction (a number of subcontractors). As a result, the model cannot be used during the maintenance of the building, and it remains mainly an artefact of the construction (Korpela *et al.*, 2015).

A special feature of 3D models as digital artefacts seems to be that they can function as tools of individual design work and collaborative modelling and of problem solving and simulation as well as being able to serve as an immediate object of attention and an evolving intermediary object to which the outcomes of the cycles of design are objectified. This is the expression of the modifiable, updatable, modular and variable nature of digital artefacts (Manovich, 2001; Kallinikos *et al.*, 2010). This changing status is compatible with the activity theoretical view, according to which an entity may gain different functions depending on its position in the structure and course of activity. In the temporal process of activity, an object can become a tool and a tool can become an object. The first transformation is most obvious when an as-designed model becomes a tool of construction. Because of the modifiability of digital artefacts, these transitions between functions seem to be much more frequent within the design activity than previously. We also conclude that the implementation of BIM has caused changes in design collaboration. The joint planning meetings focused on problem solving and the simulation of planning solutions using combined models are a step from the previous planning practice in which disciplinary models are transferred between designers. In addition, we suggest that this work with a combined model has given birth to a novel modality of collaborative spatial thought and problem solving. The development of software and standards is likely to make the collaborative design increasingly fluent and versatile.

One of the central themes in dealing with the object has been the expansion of the object. Following Knorr-Cetina's (2001) view, we can suggest that the share and importance of design and planning – the open, or 'ideal' element of productive activities – are increasing. This is connected to the vision provided by the concept of co-configuration and the need for designer–producer–user collaboration: for design to be good quality, knowledge of the needs of the users must increasingly be included in the models. This functional and social expansion is especially evident in BIM and its uses. These uses will be expanded in design by increasingly including users and clients, construction personnel, authorities, subcontractors and the suppliers of construction materials. BIM-related software is constantly being developed to allow this: software for the modelling of energy consumption, environmental issues, occupational safety, project management, cost calculation and for the ordering and delivering of materials and building elements. A major condition for these expansions is that the different groups learn together to deploy the potentialities of these technologies by creating and negotiating novel solutions in their collaborative use.

Biographies

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- 1 “Thus, the object of activity is twofold: first, in its independent existence as subordinating to itself and transforming the activity of the subject; second, as an image of the object, as a product of its property of psychological reflection that is realised as an activity of the subject and cannot exist otherwise” (Leontjev, [1978](#), 52).
- 2 Nardi ([2005](#), 40) argued that ‘the notion of constructing an object is ambiguous in much of the activity theory literature’. According to her, ‘we speak of constructing an object when we mean *formulating* it, that is figuring out what it should be. *Instantiating* an object then refers to the work that goes into realising a particular of object, to achieving an outcome’. We will show later that in construction design, the collaborative creation of a 3D model system is by its nature an elaboration of a ‘special’ material object involving extensive problem solving related to the forthcoming building. It can be regarded as an outcome of design activity and an evolving intermediary artefact preceding the construction process.
- 3 A European construction report found that in 1995, up to 60 consulting and contracting firms may be involved in a typical 50 million pound project (Crotty [2012](#), p. 26).

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