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Contribution of neurosciences for understanding the role of trust in IT-supported collaborative design environments

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Mutual trust is the cornerstone of cooperation, all the more so in virtual contexts. Damasio in his seminal book "Descartes' error" explains how emotions and feelings impact our beliefs and attitudes, and, as a consequence, trust in social interaction. In many cases collaborative design means not only exchanging ideas to yield a shared solution, but also accepting to learn from other design team members. This holds specifically true in projects requiring multidisciplinary competencies such as the construction sector. It is shown how neurosciences can contribute to underpin the framework of learning processes and help understand how to deploy suitable communication and learning conditions in IT-supported collaborative environments found in the multidisciplinary construction sector. Recommendations are produced to supplement the conceptual model already designed by Carrara and Fioravanti.

Keywords: trust, cooperation, virtual environments, emotions, feelings, learning

1 Introduction

It is widely acknowledged that the importance of digital faceless communication will continue to increase in the coming years. E-enabled collaboration between business actors has already proved to be a key driving factor for changing organisational business patterns of many economic sectors. Design, production and distribution channels of products and services will be more and more affected by this upheaval. The technology called 'cloud computer' is expected to thrust an even more drastic change in the ways and means how business processes are supported by IT, and, as a consequence, are structured and run. Mobile working environments will avail of this technology creating fully-fledged mobile virtual real-time working environments.

The construction sector is quite challenging because during the whole life cycle of a project, i.e. designing, building and maintaining any type of constructed entity, many stakeholders having different cultural and technical backgrounds are involved over a long period of time, as a matter of fact the very lifetime of the constructed entity, which spans over decades.

As communication is now carried out in many circumstances by internet-based implements, often called virtual spaces,[1] the main challenge is to incorporate "trust features" through digital technology artefacts in order to mirror as much as possible human face-to-face behavioural patterns. In addition these artefacts must be designed to offer a high degree of flexibility, enough to cope with a wide variety of schools of thought and human attitudes, in order to support relationships that require a large degree of trust to yield successful conclusive results.

The purpose of this paper is to investigate how neurosciences can contribute to a

1 Rayport, J.F. & **Sviokla, J.J**. (1995). Exploiting the virtual chain, Harvard Business *Review* 73:11-12, pp 75-85

better understanding of the attitudes of individuals embedded in virtual collaborative spaces and exposed to decision-making processes for design purposes. Design activities are ruled by dynamic mental states that can be referred to learning, and as such deserve special attention. The realm of architecture exemplifies this sort of context through the wide spectrum of stakeholders involved and the long range effects of decisions made in the design stages.

2 key definitions

2.1 Trust

Trust is defined in the Oxford dictionary as "confidence, strong belief in the goodness, strength and reliability of something or somebody". It can also be described as "the degree of credibility, which is the amount of credence that is rational to assign to a more or less uncertain situation". This type of situation is inferred from some kind of interconnection between occurrences of two classes of events, i.e. facts and beliefs. A fact is something observable that happened and is accepted as such by a community of people, i.e. historical facts or economic facts. Beliefs refer to the interpretation of facts by reference to innate and acquired knowledge. They are used to engineer and develop future courses of action. The phrase heard or read is A, and it is understood B. In other words inference from a group of events (facts) to other events (beliefs) demands a sort of binding between varieties of occurrences. This description can be used to devise more or less sophisticated models representing how trust is involved in human mind.

The main features of trust in human activities can be described as follows.

- Trust is not blind: we do not trust people we do not know.
- Trust needs boundaries: unlimited trust is unrealistic.
- Trust is tough: reliability is a key issue. When commitments of any sort are not fulfilled relationships are damaged.
- Trust demands learning: situational conditions change and new environments have to be apprehended accordingly.
- Trust is touch: the more virtual a community becomes, the more its people need to keep in touch and meet in person.
- Trust requires direction: direction of action and motivation are the feat of leaders, since trust has to be built and managed over time.

We are aware that the word "belief" has been interpreted in different ways in the realm of philosophy and that its translation in other Indo-European languages (German, French, Italian, Spanish among others) appears difficult. It is outside the scope of this paper to discuss this issue.[2] We interpret it within the framework of what is called "the philosophy of mind" in the Anglo-Saxon context.[3] According to Hume's book (A treatise of Human Nature-I, I sec 7) a matter of fact is "easily cleared and ascertained" and is closely correlated with reality: "if this be absurd in fact and reality, it must be absurd in idea".[4] These matters of fact are objects of belief: "it is certain that we must have an idea of every matter of fact which we believe….When we are convinced of any matter of fact, we do nothing but conceive it" (Hume I, III sec 8).[5] In his book "Enquiries concerning human understanding and concerning the principles of morals" Hume confirms that matters of fact and relations of ideas should be clearly distinguished: "All the objects of human reason or enquiry may naturally be divided into two kinds,

2 Cassin, B. ed (2004).Vocabulaire Européen des Philosophies, Seuil Le Robert

3 Hume, D. (1739-1978). A Treatise of Human Nature-I, I section 7, Nidditch ed, Oxford University Press

4 Hume, D. (1777-1975). Enquiries concerning human understanding and concerning the principles of morals, Nidditch ed, Clarendon Press, Oxford, p 25

5 Hume, D. (1739-1978). op cit I, III section 8

to wit, relations of ideas and matters of facts ….Matters of fact, which are the second objects of human reason, are not ascertained in the same manner; nor is our evidence of their truth, however great, of a like nature with the foregoing".[6] The contrary of every matter of facts is still possible.

A lot of theories have been developed to explain how people process information. All of them posit that communication depends on how messages are understood and judged. They address three interleaved accomplishments, i.e. interpreting, organizing and judging received information. The main mechanisms driving human thought and action and considered by these theories are meaning assignment, reasoning and cognitive consistency. They are well explained by an integrant variable called ''attitude'' reflecting how stakeholders behave when conducting negotiations in a broad sense of this word, i.e. communicating with other actors.

An attitude is a predisposition to act in a positive or negative way toward an object. The information-integration approach is one of the best credible models of the nature of attitudes and attitude change.[7] [8] [9] According to this approach all information has the potential of affecting one's attitude. Two parameters have to be considered to understand the degree of influence of information on attitudes, i.e. *how* and *how much* parameters. The *how* parameter is intended to evaluate the extent to which information supports one's belief or not. The *how much* parameter tries to measure the weight assigned to information. Attitudes are a function of a complex factor involving beliefs and evaluation. It is important to distinguish between two types of belief, i.e. belief in an object and belief about an object. When one believes in an object one predicts a high probability of the object existing. Belief about is the predicted probability that particular relationships exist between one object and others. Beliefs are embodied by the hundreds of thousands of statements we make about self and the world.

Attitudes change when beliefs are altered as new learning occurs. An attitude toward an object equals the weighted sum of each belief about that object times its evaluation. Rokeach has developed an extensive explanation of human behaviour based on beliefs, attitudes and values.[10] [11] According to him each person has a highly organised system of beliefs, attitudes and values, which guides behaviour. From Rokeach point of view values are specific types of beliefs that act as life guides. He concludes that people are guided by a need for consistency between their beliefs, attitudes and values. When some piece of information brings about changes in attitude toward an object or a situation inconsistency develops and generates mistrust. Another facet of trust and belief is linked to certainty and probability. Probability is commonly contrasted with certainty. Some of our beliefs are entertained with certainty, others there are of which we are not sure.

2.2 Virtual collaboration

The main characteristic of the virtual space, referring to collaboration, is that actors meet:

- *Out of sight*: dealing with systems that are proxies of people we do not see, and discussing with "faceless" partners
- *Out of touch*: the user has no physical control, and a narrow bandwidth for communication (no voice, no sight)

Paraphrasing a quote from Nietzsche could be appropriate to explain the user's

6 ibid

7 Anderson, N.H. (1971). Integration theory and attitude change, Psychological Review 78 p 171-206

8 Fishbein, M. & **Ajzen, I.** (1975). Belief, Attitude, Intention and Behaviour, Addison-Wesley, Reading

9 Wyer, R.S. (1974). Cognitive Organization and Change, Erlbaum, Hillsdale, New Jersey

10 Rokeach, M. (1969). Beliefs, Attitudes and Values: a Theory of Organization and Change, Jossey Bass, San Francisco

11 Rokeach, M. (1973). The Nature of human Values, Free Press, New York

feeling of remoteness: *"the virtual space is the place where man remembers his first great fears"*.
Virtual collaboration represents man-machine interaction where technical systems perform hidden procedures to achieve the user's goal.
A psychological aspect of the virtual space is the perceived invisibility of the system a human is interacting with. This invisibility can be ascribed to the properties of the system itself in relation with its mental representation by users. Invisibility has four dimensions, i.e. the human, the system, the task and the environment. The degree of invisibility is hard to assess and depends on the individual involved. Questions can help in understanding how an individual reacts to invisibility. The answer to this simple question "what are you doing?" reveals the basic relationship between the tool, the user and the task. If to this question already the tool is mentioned, then the tool is central to the user's mind. If only the task is mentioned, the tool has some degree of invisibility to the user. By detailing the question further: "how are you doing the task?" and "what steps are you performing to accomplish the task?", eventually the tool will be mentioned. These questions allow for discriminating between what is central in the mind of users. According to the spectrum of possible user attitudes software designers face a dilemma. The choice is between on one hand enhanced integration of function capabilities and making the digital system more invisible, and on the other hand less integration of function capabilities and making the user more involved in the deployment of function capabilities.
Another issue to address refers to negotiations. They are the very fabric of business life. A negotiation is a discussion aimed at reaching an agreement. When disagreement of a sort between collaborating parties arises, several strategies are open to try to resolve the issue by determining what the fair or just outcome should be. One might be that a set of transaction rules might have been defined covering eventualities of conflicts and actions for settling disputes. This situation can be formalized by a negotiation protocol. A second strategy is seek the advice of an impartial referee. A third strategy would be to conjure someone up in the imagination, a hypothetical referee. When the hypothetical agreement is used to solve conflicts, it has to be supposed that some sort of hypothetical contract is to be made under explicit or, more often, tacit conditions. In general tacit conditions prevail because of "asymmetric ignorance" between the parties involved.

3 Emotions, feelings and trust

In this section we heavily draw on the ideas introduced by Damasio in his well-known book Descartes' error to contend that trust is a major parameter to make virtual collaboration work.
In his book's introduction Damasio writes: "the strategies of human reason probably did not develop, in either evolution or any single individual, without the guiding force of the mechanisms of biological regulation, of which emotion and feeling are notable expressions. Moreover, even after reasoning strategies become established in the formative years, their effective deployment probably depends, to a considerable extent, on a continued ability to experience feelings".
This is one of the main tenets that Damasio unfolds in his book: the body and the mind are not independent, but are closely correlated through the brain. The brain and the body are indissolubly integrated to generate mental states. Let us

elaborate on two key words mentioned in the quote mentioned above, i.e. emotion and feeling.[12]

Damasio distinguishes between primary and secondary emotions.[13] Primary emotions are wired in at birth and innate. Secondary emotions "occur once we begin experiencing feelings and forming systematic connections between categories of objects and situations, on the one hand, and primary emotions, on the other." Secondary emotions begin with the conscious consideration entertained about a person or situation, and emotions develop as mental images in a thought process. They cause changes in the body state resulting in an "emotional body state". Feeling is the experience of those changes. Some feelings have a major impact on cognitive processes. Feelings based on universal emotions are happiness, sadness, anger, fear and disgust.

The relationships between emotion and feeling are summarized by Damasio in this phrasing: "emotion and feeling rely on two basic processes: (1) the view of a certain body state juxtaposed to the collection of triggering and evaluative images which cause the body state ; and (2) a particular style and level of efficiency of cognitive process which accompanies the events described in (1), but is operated in parallel".[14]

Feelings may change beliefs and as a consequence attitudes as explained in the previous section. On the basis of theories mentioned above, events from emotions to attitudes follow this orderly sequence: emotions causing specific body states that generate feelings by cognitive processes and impact on beliefs and attitudes.

Among the feelings based on universal emotions, mutual fear can be considered as one of the major psychological factors affecting relationships in collaborative networked environments. Fostering trust appears to be a relevant counter measure to mutual fear.

A general argumentative review of the biology of emotional states is given in Kandel's panoramic autobiography.[15] [16]

It is relevant at this point to bring back to memory that the brain containing one hundred billion nerve cells interconnected by a hundred trillion links is not an independent agent. It is part of an extended system reaching out to permeate, influence, and be influenced, by every corner of our body. All our physical and intellectual activities are controlled directly or indirectly by the action of the nervous system of which the brain is the ultimate part. The brain receives a constant flow of information from our body and the outside world via sensory nerves and blood vessels providing it with real-time data.

When discussing about the brain we are confronted with a paradox of self referencing: we think about our brain with our brain! We are caught in a conundrum difficult to escape and shedding a light of partiality on our own current and future in-depth knowledge of brain processes.

4 The learning dynamics of mental states and attitudes in collaborative design activities

In this section we resort to Lewin's field theory to analyze how emotions, feelings, trust are dynamically articulated when collaborative design activities are engineered.[17]

The fundamental construct introduced by Lewin is that of 'field'. All behaviour

12 Damasio, A.R. (1994-2006 revised). Descartes's Error- Emotion, Reason and the Human Brain, Vintage Books, London, p XXII

13 op cit p 134

14 op cit p 162

15 Kandel, E.R. (2007). In Search of Memory – The Emergence of a new Science of Mind, WW Norton, New York, Chapter 25

16 Kandel, E.R. (2007). op cit p 479

17 Lewin, K. (1951). Field Theory in Social Science, Harper and Row, New York , 16

in terms of action, thinking, wishing, striving, valuing, achieving…is conceived of as a change in some state of a field in a given time unit. In the realm of individual psychology the field is the life space of the individual. The life space consists of all the beliefs and facts that interact to produce mental states resulting in attitudes at any given time. Lewin's assertion that the only determinants of attitudes at a given time are the properties of the field at the same time has caused much controversy. But it sounds reasonable to accept that all the past is incorporated into the present state of the field under consideration. To put it in a different wording only the contemporaneous system can have effects at any time. As a matter of fact the present field has a certain time-depth. It includes the 'psychological' past, 'psychological' present and 'psychological' future which constitute the time dimension of the life space existing at a given time.[18]

All attitudes depend on the cognitive structure of the life space that includes, for each member of a design team, the other stakeholders of the design team. When exposed to the design suggestions of other team members or their critical judgement of his own design work, any member develops either a conditioned reflex based on his innate and/or acquired knowledge embedded in his brain's neural connexions or branch out into emotional expressions according to the way the received information is appraised as a reward or a threat. This last case occurs if he feels he cannot secure the right pieces of knowledge to produce an appropriate reaction. Wilson, Gilbert and Centerbar wrote "helplessness theory has demonstrated that if people feel that they cannot control or predict their environments, they are at risk for severe motivational and cognitive deficits, such as depression."[19]

If one design team member trusts the other design team members, his motivation is strengthened to embark on a learning process to better his acquired knowledge. Learning engages imagination, demands concentration, attention and efforts. Conscious awareness is fully involved.

Two learning concepts have been developed, i.e. one derived from the Bayesian school of thought and the other from connectionist theories. The Bayesian method provides a cognitive mechanism to solve non-well defined problems. It is appropriate here to explain in some details the paradigm underlying the Bayesian approach. It relies on using information to engineer statistical inference about unknown quantities to make prediction of 'future' outcomes and eventually to take various courses of action. One important source of information is the data pertaining to the issue under study, but there is an undeniable role for non-data-based information. Information can also come from 'subjective' views that there is a structure underlying the unknowns. Unknown quantity is a generic term referring to any value not known to the investigator. In an active environment future outcomes of actions (as yet unrealized) are properly regarded as unknowns.

The goal of the Bayesian method is to make inferences regarding unknowns given the information available that can be partitioned into information obtained from the current data as well as other information obtained independently or prior to the current data, which can be assigned to the investigator's current knowledge. The more or less assured certainty of the expected future states of nature is encoded as probability estimates conditional on the information available.

Within this framework of thought learning relies on the repetitive running of a

18 ibid

19 Wilson, T.D. et al (2003). Making Sense: The Causes of Emotional Evanescence. In: Brocas, I. & Carillo, J. eds, The Psychology of Economic Decisions, Rationality and Well-being, Volume I, Oxford University Press, New York

trial and error process. In the inceptive step the distribution of a priori subjective probabilities with respect to the future possible states of nature and their properties is chosen on the basis of innate and acquired knowledge to build a representation of the likely outcome of future action. This procedure draws on the Bayes' theorem. When the factual outcome happens, its compliance and/or discrepancy with the expected effect are analysed and memorized producing incremental knowledge coming from experience.

Another approach called connectionism has been worked out in the period 1940-65 by pioneer researchers such as Frank Rosenblatt and Oliver Selfridge. It is intended to model mental and behavioural phenomena by processes emerging from the activation of networked simple processing units like neurons. One of the most attractive features of connectionist constructs is their ability to learn. This is accomplished by adjusting the link weights connecting the various units of the system, thereby alternating the manner in which the network responds to inputs. The difference between the actual response and the target response can be gradually reduced by adjusting the link weights. Within this framework of thought Holland et al have proposed a pragmatic and inductive learning process. Induction qualifies the sense of knowledge acquired by practice and leads to mental knowledge models resulting from condition-action rules. Three induction processes are put forward by Holland et al:[20]

- generating rules by inference processes
- grouping rules to account for co-variation observations and the temporal existence of relationships
- applying the knowledge gained from experience in one domain to analogous situations in other domains

How is learning explained by neurosciences? Neuroscientists contend that the brain cannot be compared with an algorithmic computing machine (Turing model).[21] The brain captures and processes sensory signals continuously in parallel. We are not consciously aware of that activity that still operates even when we sleep. But it appears that the human brain is not able to make and deliver two decisions simultaneously in spite of the fact that it receives and interprets continuous sensory stimuli from different sources with different mechanisms.

The central issue raised is: how to make these two views compatible? How are cortico-thalamus networked units massively operating in parallel organised to produce the impression of serial processing? The algorithmic model favoured by mathematicians is accepted to represent slow complex serial operations requiring conscious effort. Dehaene et al hypothesised a neural workplace where the learning of elementary tasks takes place gradually by trials and errors with conscious awareness and effort.[22] [23] In fact it is a matter of progressive and selective programming of action rules by letting appropriate behavioural rules be found out by a trial and error procedure. In the view of Changeux brain hardware and software make concurrent progress interacting with the outside world according to the Darwinian model. That means that the brain exhibits some sort of plasticity. It is interesting to notice that Lewin's construct of field and life space is not inconsistent with the concept of neural workspace and can be viewed as another facet of the same product of thought. [24]

Knowledge acquired by learning must somehow be retained physically in the brain. This capability is assigned to long-term memory. Different kinds of mem-

20 Holland, J. et al (1986).Induction, The MIT Press, Cambridge Mass

21 Dehaene, S. (2007). Le cerveau humain est-il une machine de Turing? In: Changeux, J.P. ed, L'homme artificiel, Odile Jacob, Paris

22 Dehaene, S. et al (1998). A neuronal model of a global workplace in effortful cognitive tasks, Proceedings National Academy of Science, USA 95:24, pp 14529-14534

23 Dehaene, S. & **Naccach,e L**. (2001). Towards a cognitive neuroscience of consciousness : basic evidence and a workspace framework, Cognition 79, pp 1-37

24Changeux, J.P. & **Connes, A**. (1992) Matières à penser, Editions Odile Jacob, p 220-221

ory are recognized. The most basic distinction is between short-term and long-term memory. Memory derives from changes in the synapses in a neural circuit: short-term memory from functional changes and long-term memory from structural changes. Long-term memory requires the synthesis of new protein.[25] This distinction between short-term and long-term memories has been confirmed by the research works which have been recently published by Lechevalier et al.[26]
According to Kandel (chapter 15) the simplest form of learning, habituation and sensitization, can be sustained with repeated training.[27] Habituation is a simple, non-associative form of learning in which a subject learns about the properties of a single, innocuous stimulus. He learns to ignore the stimulus, resulting in decreased neural response to it. Sensitization is another type of non-associative learning in which exposure to a noxious stimulus produces a stronger reflex response to other stimuli, even innocuous ones. In collaboration with Squire Kandel, winner of the Nobel Prize for medicine in the year 2000, has worked out a phased procedure to explain how a learning process proceeds. In the first phase sensory information is encoded in the short-term memory where it can be stored for 30 to 60 minutes. In the second phase some part of the stored data items are transferred to the long-term memory. How the stored data items to transfer are chosen remains an open question.
The Bayesian approach to cognition is reinforced by Berthoz's opinion (that memory has a pivotal role in thinking ahead and predicting yet unobserved courses of action: "it allows to compare sense-data to the consequences of past actions and to foretell the consequences of the current action.[28] Recent findings show that this dual control is executed by the thalamus processing sense-data." This implies a probabilistic reasoning in line with Bayes' formula linking a predictive distribution of unobserved data derived from prior beliefs and a posterior distribution reflecting the combined set of prior beliefs and current sense-data.[29]
All these arguments lead to posit that the Bayesian and connectionist approaches are the two sides of the learning process. From trials and errors driven by subjective probabilities connections in the cortico-thalamus networks come into being during the learning process and develop for action what is called conditioned 'fast tracks' or 'heuristics'.[30] [31] These 'fast tracks' or 'heuristics' operate when knowledge accrued by learning is used to trigger the decision-making process for action.

5 How to pitch a plan to foster trust in the construction sector?

Trust is not a specific feature of collaborative business environment. It is the very fabric of social life: construct a jointly useable asset, collaborate in political activity, do business, enter marriage, create a partnership ...
Two issues have to be addressed to understand how the lack of trust stifles human activities:

- What kinds of organisation are capable of wielding influence for fostering mutual trust that is the cornerstone of cooperation?
- Under what circumstances would the parties who have come to agreement trust one another to keep their word?

As far as the first issue is concerned, we shall focus on technical environments such as what is encountered in complex building project. In such multicultural contexts we think that sharing knowledge is an objective basic answer uncol-

25 Kandel, E.R. (2007). op cit Chapter 16-17
26 Lechevalier, B. et al (2000). Imagerie fonctionnelle des hippocampes dans le syndrome de Korsakoff, Bulletin de l'Académie Nationale de Médecine, pp. 191-197
27 Kandel, E.R. (2007). op cit Chapter 15
28 Berthoz, A. (2009). La simplexité, Odile Jacob, Paris, p 28
29 ibid
30 op cit p 76
31 Taleb, N.N. (2008). The Black Swan, Penguin Books, p 81

oured by the wide variety of possible subjective opinions and attitudes of the stakeholders involved. A Babel disorder must be shunned at all costs by securing workable communication channels through a common knowledge base.

Carrara & Fioravanti have worked out a model for improving the design quality of complex building systems.[32] The salient feature of this model is the combination of specialist knowledge structures and a common knowledge structure containing all the data items shared and understood by all the project's stakeholders. The concept is portrayed in Figure 1. This is an excellent example of what should be developed.

32 Carrara, G. & **Fioravanti, A**. (2009). Improving design quality of complex building systems by means of ICT enhanced collaboration, Collaborative Working Environments for Architectural Design, Palombi Editori

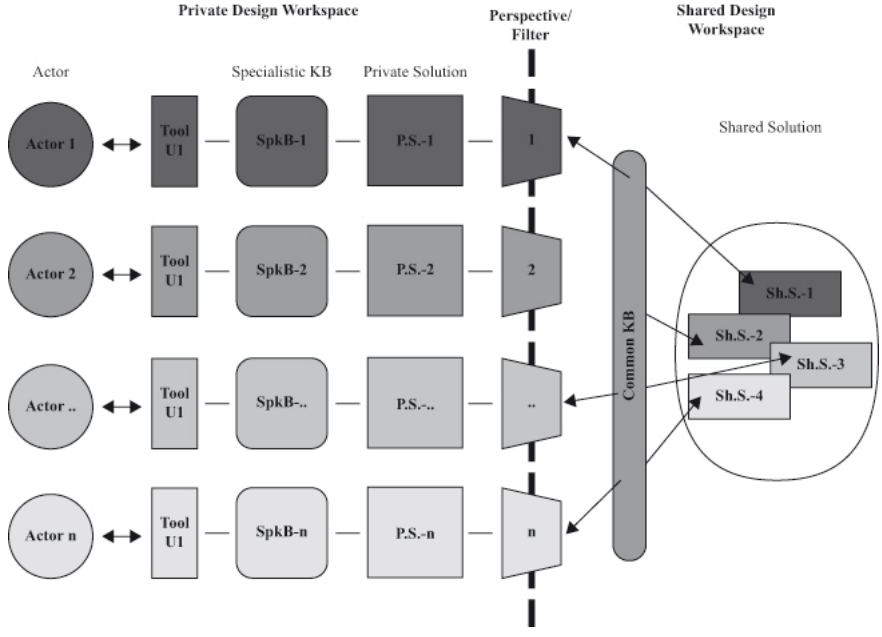

Figure 1 An actor relates his/her own private design solution with an other actor's ones through a Common Knowledge Base

The second issue is more difficult to deal with because of the involvement of emotions, feelings, beliefs and attitudes. To make operational sense one's word must be credible if it is to be believed. Mere promises are not enough. If the collaborating parties are to trust one another to keep their commitment, matters must be so arranged that:

- at every stage of the agreed course of actions it would be in the interest of each party to keep his or her word if all others were to plan to keep their word;
- at every stage of the agreed course of actions, each party should believe that all others would keep their word.

If the two conditions are met, a system of beliefs that the agreement will be kept would be self-confirming.

Notice that condition (2) on its own would not do. Beliefs need to be justified. Condition (1) provides the justification. It offers the basis on which everyone could in principle believe that the agreement will be kept. Condition (1) on its own would not do either. It could be that it is in each one's interest to behave opportunistically if everyone believed that everyone else would behave opportunistically.

These two conditions embody a common idea: begin by cooperating and continue to cooperate so long as neither party has broken their word, but withdraw cooperation permanently following the first defection from the agreement by either party. Withdrawal of cooperation is the sanction. That should be engineered by reporting procedures letting all the parties check whether the commitments which have been agreed on are fully and timely fulfilled.

The approach described in the previous paragraphs is underpinned by the classical mental mechanism called 'anchorism'. We lower our anxiety about uncertainty by producing reference points and we "anchor" on them. This mechanism was discovered by the pioneers of the psychology of uncertainty D. Kahneman and A. Tversky. We use reference points in our brains and start building beliefs around them because less mental effort is required to compare an incoming sense-data to a reference point than evaluate it in the absolute. Neurobiologists differentiate between parts of the brain, the cortical part, which we are supposed to use for thinking and which distinguishes us from other animals, and the fast-reacting limbic brain. That limbic brain reacts so quickly that it takes some time before we become consciously aware of the very reaction in progress. This delay known as the "half second lag" has been studied by Libet.[33] His findings raised the issue of free will. When we receive information that contradicts our reference points, are we able to control our reactions? If not our reactions can hurt and generate highly damaging distrust. That is why it is recommendable to establish clear collaborative protocols and procedures to provide design team members with tools (charts, score boards, drawings … on websites) allowing not only for exchanging knowledge, fostering mutual learning but also for reducing uncertainty about the work in progress, the timely targeted results.

6 Conclusion

The purpose of this paper is to gain a deeper understanding of human behaviour in virtual collaborative environments by drawing on the findings of neurosciences and related domains in social sciences. Without reaching ultimate understanding of the intricacies of human behaviour, we have however managed to come to clear conclusions that a limited number of key factors are required to secure the successful running of virtual design collaborative environments. First of all emotions, feelings and trust are closely interwoven to motivate all the stakeholders of a design project and to keep them mutually productive. In the second place trust must facilitate sharing knowledge and incite to learning to deliver improved shared knowledge for the benefit of each stakeholder. This point is crucial in multicultural technical contexts such as the construction sector. Thirdly it is of paramount importance to counteract uncertainty pertaining to the courses of action taken by the various stakeholders and their outcomes by well defined and properly fulfilled protocols and procedures. It has to be born in mind that transactional interactions take place in faceless environments with a narrow communication bandwidth.

In order to shun mutual fear in collaborative virtual working environments, it is essential to provide all the actors with a common knowledge basis. A conceptual model achieving this purpose in the construction sector has been developed by Carrara and Fioravanti.[34] A special feature of this sector is its multicultural technical context. That means that actors having a wide variety of technical compe-

33 Libet, B. (2004). Mind Time: The Temporal Factor in Consciousness, Harvard University Press, Cambridge

34 Carrara, G. & **Fioravanti, A**. (2009). ibid

tencies have to collaborate to yield a useable final product with compelling characteristics.

We suggest that Carrara and Fioravanti model should be supplemented by reporting protocols to secure mutual trust by reinforcing the project actors' beliefs in their partners to fulfil the commitments which have been agreed on.

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