A comparison between rut depth values obtained from 2D and 3D Finite Element modelling

Mohammad Fahad
Department of Transport Infrastructure
Szechenyi Istvan University
Gyor, Hungary
Fahad.mohammad@sze.hu

Richard Nagy
Department of Transport Infrastructure
Szechenyi Istvan University
Gyor, Hungary
Nagy.richard@sze.hu

Abstract—Both 2D and 3D finite element models have been used to simulate rutting or fatigue cracking induced by heavy loads on pavements. In this article rutting caused by autonomous trucks moving under zero wander mode have been tested using a 3D and 2D model and results are compared. Vehicle speeds of 50 Km/h and 90kmh are considered and the results are compared simultaneously for both 2D and 3D models. Results show that higher magnitude of rut depth occurs when simulation are run using a 2D model with an average difference in rut depth of 2.3 mm.

Keywords—ABAQUS; Rutting; Power Law Model; 2D and 3D Modelling

I. BACKGROUND AND LITERATURE REVIEW

Rutting predctions in previous literature include the use of both 2D and 3D FE models. Ali et al. have used a viscoplatic constitutive model in 2D plain Strain FEM to evaluate the nonlinear behvaiour of pavements under complex traffic conditions. Ali et al. identified that the rutting phenomen is higly affected by traffic speed and lateral wander of vehicles by using a finite elemnt model [1]. AlKhateeb et al. also used the 2D FEM to investigate rutting using in pavements using Pekkined and Witczak Model and he identified that temeprature, tire pressure and subgrade strength can highly affect the rut depth of asphalt layers. The post model validation sensiticity analysis indicated that with increase in temeprature and tire pressure and decrease in subgrade strength, the rut dpeth would increase siginifacntly [2]. Sadeghnejad et al. used the 2D FEM by incorppaerting the Creep model developed by Hua 2000 to predict the rutting behaviour of Glasphalt mixtures and the effect of temperature ansd stress on these mixtures. It was identified that the presented creep model int he study succeefully evaulate the rutting prediction of glasphalt mixtures [3].

Huang et al. also utilized the 3D FE model in which the time hardening version of creep power law model was used to determine rutting on of steel deck pavements. The simulation results were later compared with the full scale aacelarted testing of Mobile Load Simulator 66 – MLS66 and it was found that the tolreance was less than 17% for loading cycles from 10000 to 50000, hence the 3D FE model in the research has a good validity [4]. Wu et al. used a deformation model for ABAQUS program by wrting a customized subroutine to predict the rutting depths of two low-volume roads, Results showed the predictions were correct based on measured rut depths [5]. Chen et al. used the 2D FE model to evaluate impacts of various lateral wander modes of autonomus trucks , it was identified that time time to reach a rut depth of 15 mm accelarated by 1.56 years and fatigue damage increase byb 146% when a zerow ander mode is used [6]. Perez et al. used the 3D FE model indetermining rutting and fatigue cracking of asphalt pavement [7]. Allou et al. used 3D FE model to predict rutting based on the concept of shakedown theory under cyclic loading for unbound granular materials. [8].

Leonardi used 3D FE model to assess the impact of aircraft loading on pavement in form of rutting under repeated cyclic loading under landing phase. Results showed good capability of model to determine rutting in the asphalt pavement [9]. Imaninasab et al. used 3D FE model to determine the reduction in rut depth caused by crumb rubber in asphalt mixture. Results showed significant reduction of top 61% in rutting under static loading conditions [10]. Saleh et al. has used the Creep and Burgers model for determing rutting in apshalt pavements using a 3D FE model. Results showed that both models predicted the permanent deformation behaviour of pavement but these models lack perfect prediction when compared to measured data [11]. 3D FEM however are expensive in terms of computational time [5].

Hua performed the compariosn of results for 2D and 3D FE model. The rut depth profiles wrere predcited using both methods for 5000 load passess and it was found that the difference in maximum rut depth in two methods was 2% which is not siginficant in terms of rutting prediction of asphalt pavements [12]. Al-Rub et al. evaluated the effects of different simplified 2D and more realistic 3D loading techniques on predicting rutting in asphalt pavement under repeated loading conditions. Papp et al. [13] has stated that 3D models use a constructive solid geometry in which a complex solid is created by combining similar objects, so in this case, results show that the 2D plane strain FE simulations significantly overestimate rutting as compared with the rutting performance predictions from more realistic 3D FE simulations [14]. Huang et al. also used 2D and 3D FE

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simulations using an elasto-viscoplastic model for asphalt pavement. Results showed that 3D FE simulations were more close to the field measurements than the simulations performed in a 2D model [15]. Table 1 below shows the literature available that includes the use of 2D and 3D models for permanent deformation evaluation in pavements.

Table 1 Summary of literature available on the use of 2D and 3D models for rutting evaluation

Authors	Year	FE Model type	Remarks
Hua [12]	2000	2D, 3D	Rutting measurement using 2D and 3D models under 5000 wheel passes
Huang et al. [15]	2001	2D, 3D	Prediction of rutting of asphalt mixtures using 2D and 3D FE analysis
Uzarowski [16]	2006	2D	Rutting measurement using Creep Powe Law model
Wu et al. [5]	2011	2D	Measurement of permanent deformation if forms of rutting for cementitiously stabilized materials using a UMAT subroutine
Al Rub et al. [14]	2012	2D, 3D	Comparison of rutting measurements under 2D and 3D FE models under elasto-viscoplastic behavior of asphalt mixture
Zhu et al. [17]	2013	3D	Rutting evaluation under standard and variable amplitude loading
Huang et al. [4]	2015	2D	Rutting prediction of stone matrix asphalt mixture using Creep Power Law model under stationary loading
Leonardi [9]	2015	3D	Permanent deformation measurement in forms of rutting for repeated aircraft landing cycles
Shanbara et al. [18]	2016	3D	Evaluation of rutting for reinforced cold bituminous emulsion mixtures
Sadeghnejad et al. [3]	2017	2D	Measured deformations in from of rutting for glasphalt asphalt mixtures
Wang et al. [19]	2017	3D	Rutting measurement under cyclic loading scenario
Imaninasab et al. [20]	2017	3D	Measurement of rutting in modified stone matrix asphalt mixtures under different percentages of SBS polymers
Saleh et al. [11]	2017	3D	Rutting prediction using the Creep and Burgers model
Chen et al. [6]	2019	2D	Measurement of permanent deformation in forms of rutting under influence of various lateral wander modes of autonomous trucks
Gamil [21]	2019	3D	Rutting behavior evaluation of modified marl soil sample using ABAQUS
Phuong et al. [22]	2019	3D	Rutting prediction of asphalt mixtures using strain hardening creep model

II. RESEARCH METHODOLOGY

A pavement having a total width of 3.5 m is assumed. As the pavement and tire assemblies are symmetric, only half the lane width of 1.75 m is considered for analysis. Since the distribution of loading under a tire is nonuniform [23] . Pavement crosssection consisting of a dual tire is shown in Figure 1.

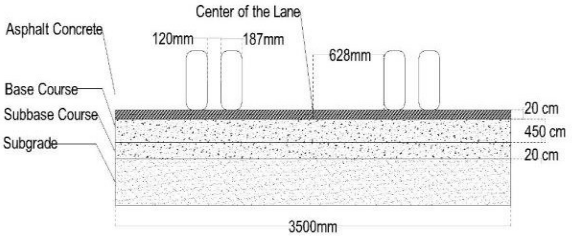

Figure 1 Pavement and dual tire details.

A. Material Parameters

Validated pavement material parameters have been taken from Cheng et al. [24] and Uzarowski [16] as shown in Table 2 and Table 3 below.

Table 2 Material parameters for Asphalt Concrete layer.

Material	Material Parameters				
AC	Elastic Parameters		Creep Parameters		
Layer Thickness	Elastic Modulus	Poissions Ratio	A (x10^{-8})	n	m

(cm)	(kPa)				
20	950000	0.41	41	1.48	-0.63

Table 3 Material parameters for underlying pavement structure.

Layer type	Thickness (cm)	Elastic modulus (kPa)	Possions ratio
Base course	40	500000	0.35
Subbase course	20	350000	0.35
Subgrade	-	60000	0.4

B. *Tire Pressure and Loading*

A nominal tire pressure of 720 kPa generated by an axle load of 75.6 kN has been used. Tire type used is conventional dual tire G159A-11R22.5 developed by Goodyear moving under a zero wander mode with its digital forrprint shown in Figure 2. Since the computer comntrolled lane keeping system follows the same computer alogrithmic and debugging based problem solving approach as mentioned by Biro et al. [25]. With a tire moving under zero wander mode, diffferences observed in rutting depth from 2D and 3D simulations are easier to analyze.

Figure 2 Digital footprint of a dual tire.

There is a nonuniform tire pressure under the tire [24],[26] and [27], hence the following tire pressure data has been taken from [26]. Figure 3 below depicts the distribution of nonuniform tire pressure under loading.

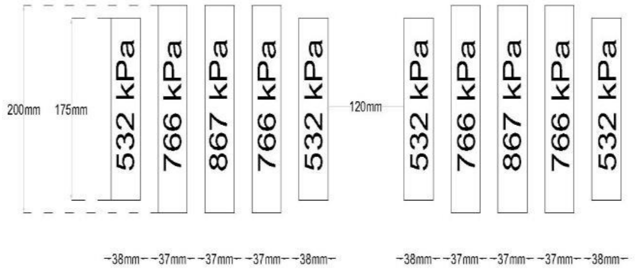

Figure 3 Dimensions and tire pressure distribution of a dual tire.

C. *Speed Selection*

Two vehicle speeds of 50km/h and 90km/h have been assumed in order to assess the impact of speed variations and total accumulated creep on the difference in results obtained from 2D and 3D models. Table 4 depicts the speed selection criteria.

Table 4 Speed selection criteria.

Speed	Scenario
50 km/h	Speed limit for heavy goods vehicles on urban roads/passing through road works zones
80 Km/h	Nominal speed of heavy goods vehicles in rural highways

D. *Use of Creep Power Law and Step loading*

Creep power law model in ABAQUS has been successfully employed to investigate the permenant deformation in forms of rutting for various asphalt mixtures in Finite Elment analysis [10], [3], [4], [12] and [16]. Power law model is simple yet suitable for determining the rutting behaviour of apshalt mixtures [16]. ABAQUS utilizes two different types of creep models namely power law model and hyperbolic sine model. In power law model, the time hardening version is used a shown in (1) below.

$$\varepsilon = A\sigma^n t^m \tag{1}$$

Where

ε is the creep strain rate

$\sigma$is the deviatoric stress

t is the total time

A, n, m are creep parameters where

$A > 0, n > 0, -1 < m < 0$

The concept of step loading time has been used to simulate different traffic speeds under various lateral wander modes originally developed by [12]. In this method, loading time corresponding to number of passess for a specific tire as shown in (2).

$$t = \frac{L_{eff}}{17.6V_s} \tag{2}$$

Where

t = time of loading

L_{eff} = effective length

V_s = vehicle speed

Hence using (2), for a truck moving at zero wander mode under a speed of 80Km/h, having an outsie tread footprint of 175 mm, time of loading for first step is 118000 seconds.A zero wander mode is selected, sine the ATs behave different than human driven vehicles in which they follow a normal distubtion of passes inside the lane as exhibted using a NeuroCar platform presented by Luimula et al. [28]. Table 5 below shows the loading time for an AT moving under a zero-wander mode.

Table 5 Step and loading time for each speed count

Speed (km/h)	Loading Time (sec)	
	Step 1	Step 2
90	118000	18000
50	189000	29000

III. 2D AND 3D FE MODEL DETAILS

2D model has been created with width of 1.75 m. For the 3D model, lateral dimensions are 1.75 m x 1.75 m.. Depth of model is kept at 4.8 m. Figure 4 and Figure 5 below show loading and boundary conditions for 3D and 2D models respectively.

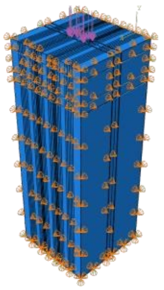

Figure 4 Loading and Boundary conditions for 3D model.

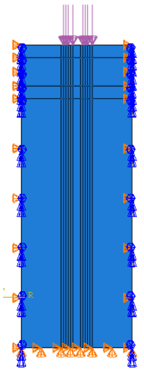

Figure 5 Loading and boundary conditions for 2D model.

The bottom parts of models have been restricted to move in all directions. 3D model used is an 8-node linear brick, reduced integration with hourglass control CPE8R. The model consisted a total of 25584 elements with an element size of 120 and CPE4R having a total of 25584 elements with an element size of 80 for 2D model. Figure 6 and Figure 7 below show the mesh details of 3D and 2D models respectively.

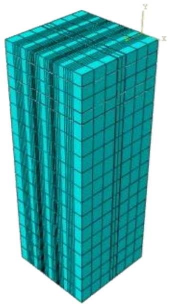

Figure 6 Mesh details for 3D model.

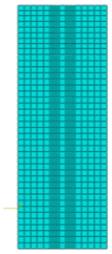

Figure 7 Mesh details for 2D model.

IV. RESULTS AND DISCUSSION

Simulations were carried out for speeds of 50 Km/h and 90 Km/h pavement design life of 15 years for a 30 million total truck tire passes for a dual wheel truck tire moving under a zero-wander mode. Figure 8 and Figure 9 below show deformation occurred at 50 Km/h for 3D and 2D models respectively.

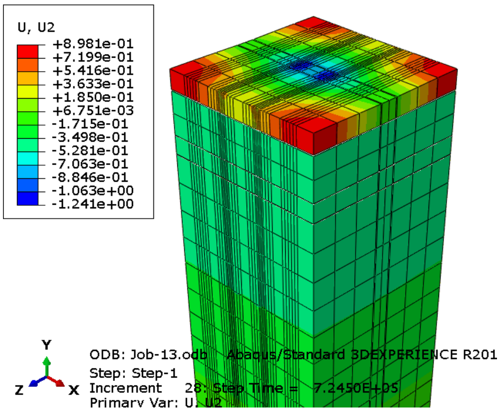

Figure 8 Deformation at 50Km/h for 3D model.

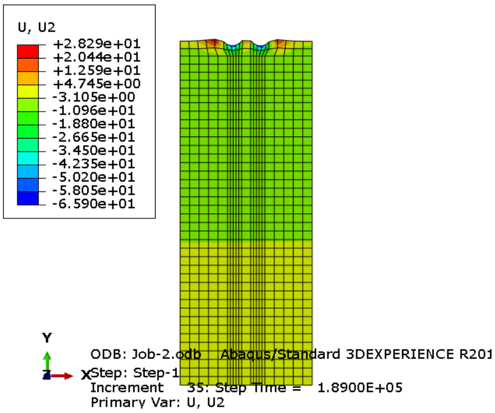

Figure 9 Deformation at 50Km/h for 2D model.

As observed, magnitude of rut depth when calculated is much larger for 2D model if visco-step loading is used in ABAQUS. In a normal scenario, an average difference in rut depth of 2.3 mm is observed irrespective of the mode of step loading used as observed from Figure 10 and Figure 11.

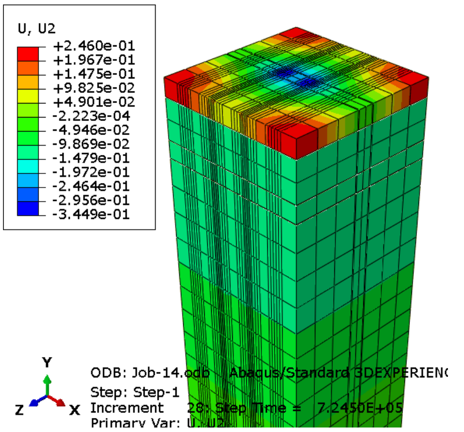

Figure 10 Deformation at 90Km/h for 3D model.

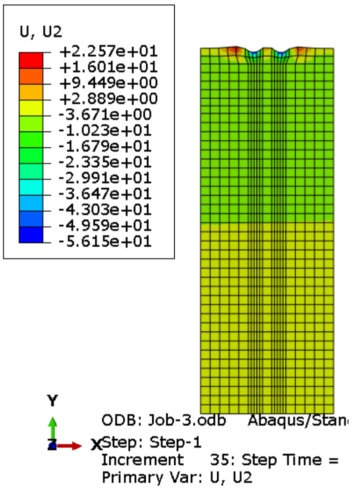

Figure 11 Deformation at 90Km/h for 2D model.

At higher speeds the difference between calculated rut depth values decreases at lower loading times as shown in **Hiba! A hivatkozási forrás nem található.**.

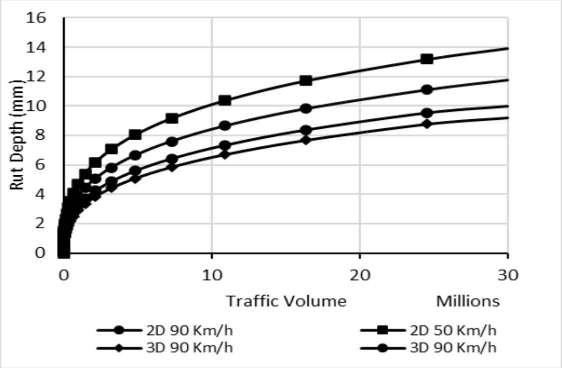

Figure 12 Rut depth for 2D and 3D models at different speeds.

2D model clearly exhibits higher rut depth values than that of 3D model. Although if only the 3D model is considered, at higher speeds the difference in rut depth values would increase depicting the nature of functionality of the 3D model. As it can be seen that in the case of 2D model, the difference between rut depth values at 90 Km/h and 50 Km/h is not that high as observed from **Hiba! A hivatkozási forrás nem található.**.

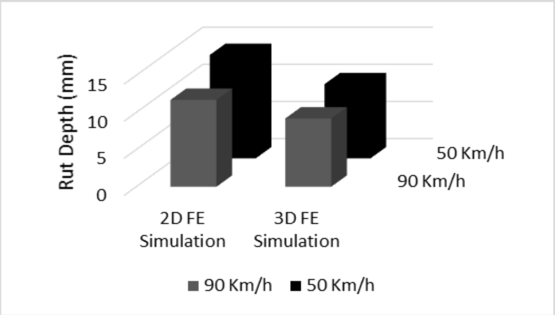

Figure 13 Rut depth under various conditions.

An average difference in rut depth of 2.3 mm occurs at speeds of 50 Km/h and the difference reduces at higher speeds of 90 Km/h to a magnitude of 1.2 mm. This effect is directly related to the nature and length of step loading and time occurring in ABAQUS. Highest rutting depth at speeds of 50 Km/h is obtained with a magnitude of 14 mm followed by 11.7 mm of rutting depth occurring at speed of 90 Km/h in case of 2D model. Rut depth in case of 2D model at speeds of 90 Km/h is still higher than that of 3D model at speeds of 50 Km/h by a margin of 0.5 mm.

V. CONCLUSIONS, FINDINGS AND FUTURE WORK

In this research the difference in results in terms of permanent deformation for a dual wheel truck tire moving under zero wander mode for 2D and 3D models has been analyzed. Simulations were carried out for step loading time equivalent to speeds of 50 Km/h and 90 Km/h. Highest amount of rut depth values are obtained using a 2D model at speed of 50 Km/h. 3D model however, yields more realistic mode of loading thereby exhibiting accurate results for permanent deformation in asphalt pavements. Below are the findings from this research.

1. 2D model exhibits increased magnitude of rut depth values.
2. An average difference in rut depth values of 2.3 mm is obtained between two models for speeds of 50 km/h.
3. An average difference in rut depth values of 1.2 mm is obtained between two models for speeds of 90 km/h.
4. Difference in rut depth values decreases while comparing results from two models at higher speeds.
5. 3D model exhibits realistic form if loading conditions thereby yielding accurate magnitude of rut depth values.

For future work, it is recommended to perform dynamic load testing on both 2D and 3D models using a MATLAB subroutine to help better understand rutting progression caused by autonomous trucks. A MATLAB subroutine command would help in performing rutting tests under different lateral wander modes used by autonomous trucks and it would also provide essential support framework for planning optimum truck platoons.

Suitability of references: In this paper a comprehensive state of the art literature review has been compiled where aforementioned authors have used both 2D and 3D models. This paper compares those practices, provides a summary and help the readers select an appropriate model for their prospective research. With comprehensive in-depth comparison of two models, we would like this paper to be accepted.

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Legal Answers to Distorted Cognitive Expectations in Platform Based Contractual Ecosystems

Deli, Gergely
Department of Legal History
Széchenyi István University
Győr, Hungary
gergelydeli@gmail.com

Abstract—**The paper suggests that distorted cognitive expectations of platform users caused by the digital ecosystem hinder the optimal contractual communications among participants. It identifies two key factors contributing to such distortions: First, the diminishing importance of mutual trust, and, secondly, the ongoing disappearance of communicative reflexivity. As a solution, the author argues that platform based contractual ecosystems (PBCEs) should be understood as quasi corporations and their regulation shall reintegrate contract law, competition law, and corporate law norms in order to effectively respond to the problems of cognitive distortions evoked by platform mediated contractual communications. By building upon former infocommunication research, the paper also outlines a three-steps ethical framework for PBCEs.**

Keywords—**platforms, cognitive distortions, contractual communication, trust, reflexivity, Roman law, ethics**

I. INTRODUCTION

Online platforms have transformed the way we make contracts. They largely contributed to the efficiency of our transactions. On the other hand, however, some of them gained unchecked power through shifting the risks from the platform to the other users (businesses offering goods or services and consumers) of their ecosystems causing negative distributional and welfare effects. These problems are normally addressed by administrative or legislative intrusions. In the recent literature we can also find arguments that the combination of contract law and competition law can more effectively respond to the threats of platforms.

This paper suggests that distorted cognitive expectations of platform participants caused by digital reality [1] exaggerate the negative consequences of abusive platform power. It argues that platform based contractual ecosystems (PBCEs) should be understood as quasi corporations and their regulation shall reintegrate contract law, competition law, and corporate law norms in order to effectively respond to the problems evoked by cognitive distortions evoked by platform mediated contractual communications.

To reach this conclusion, I first demonstrate how PBCEs are different from the former linear contractual relationships and define three main factors why PBCEs cannot be effectively regulated by the existing, fragmented legal remedies. In the second step I briefly describe an ancient Roman contractual ecosystem and compare it to today PBCEs. The differences will highlight the distortion of cognitive expectations present among the users of online platforms because of the diminishing importance of mutual trust. In part III, I make clear why reflexivity, which is also disappearing from platforms, plays an important role in legal communications. In the fourth section I make clear how the Roman law examples help us to understand that digital platforms need a more holistic legal approach, combining remedies from different dogmatic areas, crossing the boundaries of contract law, competition law, and corporate law to make digital marketplaces safer from a cognitive viewpoint. In the closing section V, I briefly describes a three-steps ethical framework for PBCEs, by building upon the previous infocommunication study by Vogel and Esposito.

II. HOW PBCES ARE DIFFERENT AND WHY ARE THEY DISRUPTIVE?

Compared to traditional, offline commerce, platforms create a contractual ecosystem along with its own standard contract rules, and connect the participants to complex contractual networks. They bring together parties who could not otherwise step into contractual relationships and transforms the traditional, linear contractual chains into contractual ecosystems. Platforms bring about a more efficient distribution of goods and services and a better allocation of resources [2]. Therefore, at least in theory, a well-functioning platform is optimal for every participant in its ecosystem [3].

In such an ecosystem, a platform has three main functions:

1. facilitators of new contractual relationships,
2. quasi legislator within the ecosystem, and
3. contractual actor itself with its own rights and responsibilities.

This triple role leads to power concentration within the platform and may trigger adverse welfare effects. Traditional economic actors do not exercise such an excessive bargaining and regulatory power. In addition, the power of a platform is not limited to the contract to which the platform is a party but extends to every contracts within the platform's ecosystem.

Let us briefly describe the three elements of the power of platforms!

Platforms as facilitators: platforms lower transaction costs and entry barriers, making new actors possible to entry the given market. In this way, they contribute to a more inclusive society, but, at the same time it may lead to unsustainable business activities. Some of the new actors may not be sufficiently prepared or informed to act rationally thereby jeopardizing their sustainable operation. It is highly questionable whether traditional contract law tools are sufficient to remedy this kind of problems [4]. European competition law seems also insufficient [5].

In addition, the majority of platform users do not have substantial, offline experiences with each other. They make tons of transactions without ever meeting the other party. Traditionally, mutual trust cemented such contractual relationships. In digital marketplaces and platforms human trust can only be present in a very moderate form (through scoring systems, recommendations, etc.). Only the distortion of cognitive expectations makes online contracting possible. Due to the way how platforms work, by enabling access to the possible widest circle of users, they contribute to the dissipation of the traditional contractual trust.

Platforms as ecosystem legislators: the contractual norms and standards prescribed by platforms do not only regulate the terms for their own contracts with other participants, that is for the contracts for the use of the platform, but also extend to every contracts within the ecosystem, e.g. to contracts made between businesses and their consumers within or through the platform. This inequality of bargaining power often results in unfair contractual clauses. For example, the explosion of micro-traders enabled by the facilitative function of platforms has highlighted the one-sidedness of the existing European competition law regime which traditionally focuses on consumer welfare and not on the interest of small, private or *ad hoc* sellers [6].

Furthermore, platforms power can be abused in such a manipulative way which seemingly enables trust to function within the ecosystem (e.g. pushing consumers to buy by signalizing them that other users are incessantly buying, etc.), in the reality, however, there is no real (i.e. human) confidence among the users. Thereby, platforms not only take advantage of but reinforce the distortion of cognitive expectations of their users already present in online environments [7].

Platforms as contractual parties: platforms are not simply providers of the contractual ecosystems, but at the same time, they are active players within the ecosystem. Their special role allows them to shift risks and costs of the platform economy to the other ecosystem actors creating a kind of *societas leonina*, unequal partnership, where the platforms only take the profits and do not have their real share from the costs [8]. Platforms rarely functions as principals or agents in the ecosystem and usually claim that they only provide the ecosystem and do not want to take any responsibilities for the transactions made within it [9]. With the traditional contract law remedies, it is hard to prevent this kind of exploitation of the platforms' power [10].

Platforms may cause cognitive problems at least in two different ways. First, by having a serious information asymmetry *vis à vis* their users, they have an unbalanced for bargaining power in the pre-contractual phase and may manipulate their users into contracting. Relevant researches demonstrated that website characteristics may be conducive to above the optimal shopping [11]. Second, platform mediated contracting strengthen the distortion of the cognitive capabilities resulting in lower expectation of trust which, in turn may lead to large amounts of miscarried transactions causing considerable financial, emotional, and social problems [12].

The main reason for the low effectiveness of existing legal regimes is that, traditionally, contract law and competition law mainly concerns situations where information deficits or unequal bargaining positions threaten the freedom of contract or the freedom to contract [13]. The current law sets up information duties [14], prohibits black-listed clauses [15] and certain abusive practices [16] and mandates substantive rules.

These solutions are, however, only effective in traditional contractual environments with bilateral relations between the platforms and their users. They may help when the realization of the first (facilitative) or the third, contractual power is abusive, but ignores the second, regulatory power of platforms. And they almost totally ignore the distortion of cognitive expectations demonstrated by the ongoing dissipation of real human trust and reflective communications in digital ecosystems.

III. A CONTRACTUAL ECOSYSTEM IN ANCIENT ROM

There is a highly contested fragment in the 6th Century AD Byzantine emperor, Justinian's legal code, called *Digesta* which can be seen to be analogous to a kind of contractual ecosystem. The factual and dogmatic situation is very unclear [17], there are several conflicting interpretations of the text which runs as following:

Cum societas ad emendum coiretur et conveniret, ut unus reliquis nundinas id est epulas praestaret eosque a negotio dimitteret, si eas eis non solverit, et pro socio et ex vendito cum eo agendum est. [18] „When a partnership has been formed for the purpose of making a purchase, and it has been agreed that one partner should license markets, that is produce markets, for the rest, and should release them from the venture, then if he fails to furnish them, he can be sued in an action on partnership and also in an action on sale."

The older translations [19] follow the text literally and understand *nundinae* as market days and *epula* as food. Thus the contribution of one of the partners was to make the others possible to attend a market and to provide them with meals for this occasion.

The newer literature [20], however, offers a quite different interpretation of this hermetic text which can be also decoded as follows. Several people entered into a business partnership with the purpose of organizing markets to buy from there. The strongest party had to license the markets where the others could act as buyers and later had to release them from the transaction. According to the text, if he did not fulfill his twofold obligations, he can be sued both with *actio pro socio* (the action for partnerships agreements) and with the action on sale, the *actio venditi*.

What was the social and economic rationality of this venture? It was a kind of trading partnership, with some working partners, who managed the buying of certain agricultural goods, while a major, tacit partner contributed the necessary capital for the realization of the market and for the purchase of the goods. The goods bought came into coownership due to the dogmatic characteristics of the Roman partnership *(societas)*. However, the major partner promised to pay off the others from the common obligation. This kind of business enterprises usually made profits by buying and later selling certain goods [21]. Here, however, the goods ended up in the sole ownership of the major partner. The presence of both the *actio venditi* and the *actio pro socio* can be easily explained: the *actio pro socio* was given if the major partner did not license the market, while *actio venditi* could be brought against him, if he forgot to buy off the goods from the others. In addition, a condemnation in an action on partnership caused *infamia* [22]. It meant an informal but serious damage to a citizen reputation.

The analogy with PBCEs are straightforward. A strong party creates the market where the weaker partners can conduct their businesses with third parties. The major party of the Roman case is the platform, the other partners are the smaller or microbusinesses operating on the platform, and the third parties are the consumers.

There is one important difference, though. The Roman legal regime did not allow the major party to totally seclude himself from the market transactions. First, the third parties could directly bring a suit against him, and, secondly, he had to form an official partnership with the microbusinesses. All of these three differences point to the fact that in the old Roman model, mutual trust has been an essential part in complex contractual ecosystems backed by the threat of ignominy.

There is no doubt that this mutual trust broke sometimes as in our case, and led to litigation. In such a case, Romans did not respect dogmatic boundaries, but enabled access to a wider range of remedies thus enabling that mutual trust may emerge from time to time again, in future transactions.

IV. THE PROBLEM OF REFLEXIVITY

The other cause leading to the distorted cognitive expectations on platforms is the lack of objective reflexivity in the contractual communication process. Standards, objective assessments, or expert knowledge are disappearing from platform ecosystems. Their places are only insufficiently filled out by individual users' comments or statistical indicators aggregated from subjective value evaluations. This leads to diminished reflexivity which seriously harms a well-informed contractual communication process. In the following I show on a Roman law example why reflexivity is of utmost importance in contractual communications.

Beside the ancient dualism of subject and object there is a field that we are now able define and that is not fully subsumable under the dual paradigm [23]. This residual field is called information. The term “information” indicates not only the mere fact of information, but also communication, i.e. the process of transmitting information. From a fragment [24] we could understand that classical Roman law was quite susceptible to reflexive processes that are more complex than dualistic relations.

In this text Ulpian described the history of the *actio negotiorum* (the claim of the agent without a mandate): before Labeo the action was given if the agent had managed to achieve the desired result *(effectum)*, that is, his activity had been effective *(utiliter)*, but later the result was destroyed due to an objective cause, beyond his control. For example, if the agent had supported a ruinous house, but, in spite of his efforts, the house later burned down. Proculus did not fully agree with Labeo. In his opinion in these cases the action can be granted only if the achieved result that was later destroyed was useful to the principal from a subjective point of view. Why should anyone pay for an activity that was not in his interest and the result of which was annihilated? Celsus ridiculed the opinion of Proculus, and highlighted that the claim of the agent is enforceable on condition that the agency was useful. According to Celsus an agency that is not in conformity with the interests of a good and diligent father of family cannot be useful.

We can here find two types of causal chain: the objective, physical causality of inanimate beings and the subjective causality of living persons. The objective causality determines what happens to the thing the agent wanted to protect from being damaged. The house gets supported, then it burns down, according to the physical causality. The subjective causality is contingent on the subjective value judgements of the agent and the principal. As Proculus pointed out, the judgements of the two persons might be different. However, there is a specific reason for the difference between these opinions, according to the subjective causality.

The first, physical causality is called non-reflexive causality, while the second, subjective causality is called reflexive causality. In the traditional approach the two types of causality are sharply separated from each other. This is because the causality of human beings is significantly more complex than physical causality, and we do not understand yet how it works. He argues convincingly that there is essentially only one causality.

Indeed, in the opinion of Ulpianus the two types of causal chain are interlinked. The agent is required to judge his own activity objectively with regard to both the physical causality and the human causality. In other words, he must have good reason to expect that based on the physical causality he will produce the desired effect, for example, the house will remain stable or the slave will recover. On the other hand, he must be able to decide what he is required to do according to the objective standard of the good and diligent father of family. It is the concept of *utiliter* that connects the two types of causality. This term means both “effective” (according to the physical causality) and “useful” (according to the subjective causality).

From another aspect, the concept of *utiliter* can also be seen as the information that links the individual subjective value judgement with the standard of the good and diligent father of family. The difference between the subjective value judgement and the objective value judgement manifests itself on a linguistic level, too. Proculus has in mind the subjective value judgement of the principal, and uses the term *dominus*. By contrast, Celsus and Ulpian think of the objective standard, this is why their texts refer to the *pater familias*. It is also evident that the objective standard is not fully accessible to the agent as subject. Even if the agent is aware of the criterion of *utiliter* activities, it is not guaranteed that he will do the right thing. There is an error in the communication process. Ulpian’s question calls our attention to the fact that sometimes the agent believes that his activity is objectively useful, but he is wrong. On the one hand, the agent reflects on the rule under which he is expected to act usefully, but on the other hand he also reflects on his own activity and thinks that the two coincide. However, this is not always true. And this is only the subjective causal chain.

In addition to that, according to Ulpian the agent is required to have good reason to think at the beginning of his activity that from the perspective of physical causality this activity will be not only useful, but effective as well. Yet the agent might be wrong not only regarding his subjective value judgement, but also concerning his assessment of physical causality. An unpredictable circumstance may later prevent the realization of the desired result. That is why Ulpian only requires the agent to have at least at the beginning of the activity good reason to expect that his activity will be useful and effective.

For now, we have seen why objective point of references and reflexivity is important in legal communications. On platforms, due their digital nature, true reflexivity is disappearing. This phenomenon exaggerates further the distortion of cognitive expectations and hinders the optimal contractual communication process.

V. CONCLUSION

In private law, free markets led to dogmatization, and dogmatization to fragmentation. The regulation of digital markets, in turn, shall reintegrate the fragmented legal institutions by embracing a more holistic approach. Otherwise, the negative welfare effects will outgrow the positive ones.

In digital environments, cognitive capacities are already distorted. PBCEs may worsen the negative consequences by the manipulative easiness of platform mediated contracting.

The traditional and fragmented contractual remedies can only insufficiently address the problems emerging with online platforms.

Legislative or administrative interventions threatens the positive welfare effects of platforms. Public law regulation should therefore be the last option. Less intrusive ways are needed, their efficacy is, however, highly questionable, especially, if we take into account the distortion of cognitive capacities caused by doing business through platform mediated contractual communications.

The most important lessons we may learn from the Romans that in the case of complex contractual ecosystems the legal remedies should minder the dissipation of mutual trust and safeguard the reflexivity of the contractual communication as much as possible by taking an integrative, holistic legal approach.

To offer a more practical contribution, in the following I briefly describe a three-steps ethical framework for PBCEs. In one of their earlier infocommunication studies, Vogel and Esposito highlighted the ethical issues surrounding new online technologies [25]. They argue that it was necessary to explore the ethical ramifications of online environments. Based upon the Roman law experiences I have analyzed in the former section, I would like to offer a three-steps framework which might effectively guide regulatory answers if they emerge in online environments such as PBCEs.

In the first step, we have to identify what modifications have been caused when a market moved from a "real" physical environment to a virtual one, if any.

In the second step, one must know whether these modifications are welfare enhancing or the opposite is the case. When calculating the costs and benefits, we should include every possible immaterial costs, like moral costs, meaning the disappearance of mutual trust or reflexivity. If, at the end of the day, the modifications are welfare enhancing, no regulatory intrusion shall be undertaken. On the other hand, if the answer is negative, in the third step we have to define the nature and method of the regulatory answer. When doing so, we have to take into account the public and private interests, and how the former ethical norms have been changed when measured along an objective-subjective norm scale.

If we conclude that some kind of regulation was needed we should give priority to soft regulatory tools. Before anything else, we should prefer ethics enhancing solution embedded in the platform's software design. By a data protection law analogy (privacy by design), we could call this principle the "ethics by design". If a more severe intrusion seems to be necessary, we should rely on self-regulation (ethical codes, etc.). Only in the most serious cases, as an *ultima ratio* shall we turn to central (or governmental), legislative measures.

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